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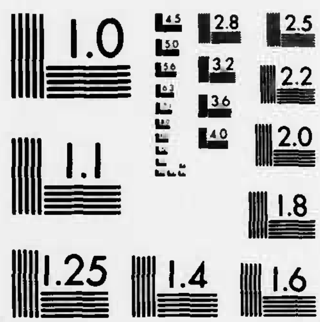

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ASSESSING AND DISPLAYING THE EFFECTS OF ELEVATED TRAPPING LAYERS IN SUPPORT OF NAVY COMMAND AND CONTROL

Prepared By:

Pierre A. Petit and Harry.D. Hamilton
Systems and Applied Sciences Corporation
Monterey, CA 93940

Contract No. N00228-83-D-3059

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Prepared For:
NAVAL ENVIRONMENTAL PREDICTION RESEARCH FACILITY
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This study examines options presently or potentially available to the U.S. Navy for assessing and displaying the existence or likelihood of elevated trapping layers (ETL) and their associated ducts over a particular geographic point or area, in support of command and control (C^2) functions related to such tactical considerations as detection, intercept, communication, guidance systems functioning and surveillance.

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EXECUTIVE SUMMARY

Study Objective. To examine the options which are now available or which could be made available to the Navy for assessing and displaying the existence or likelihood of elevated trapping layers (ETLs) and their associated ducts over a particular geographic point or area.

Background. Surface-based ducts resulting from ETLs generally give extended detection, intercept and communication ranges for frequencies above 100 MHz when both the transmitter and receiver or radar and target are near to or within the duct. Elevated ducts from ETLs can affect air-to-air surveillance, communication, electronic warfare, or weapons guidance systems. Thus information concerning the presence, coverage and vertical extent of such ducts is of interest to Navy command and control (C^2).

Summary Findings. The Navy's operational ability to forecast ducting conditions over the horizon and into the future is limited. But, the prospects for skillful ETL forecasting for the fleet from a central site are high if the potential of prediction models already installed at the Fleet Numerical Oceanography Center (FNOC) is pursued.

On-scene ETL forecasting ability could also be provided if the best of the planetary boundary layer (PBL) prediction models were converted for use on shipboard computers. There are instruments (radiosondes and refractometers) which satisfactorily observe the presence or absence and the strength of ETLs, but they require radio transmission or aircraft launch and recovery. A completely passive measurement system would be a valuable fleet asset.

There are a variety of options available for displaying the extent and effect of ETLs, but the final choice from among a large sample set of products like that presented in this report will depend on the level of tactical command and control and on the commander's personal preference(s).

<u>Summary Recommendations</u>. With respect to ETL support for C^2 from the central-site (FNOC):

- The potential for ETL forecasting based on output from both the Navy's global and regional atmospheric prediction models should be thoroughly explored.

- The display options presented in this report should be forwarded to the Regional Oceanography Centers for their comments and suggestions concerning their key C^2 customer's preferences.

- Fleet access to FNOC ETL predictions - especially those which could result from the new local prediction model - should be improved and encouraged.

With respect to ETL assessment and display on-scene:

- Development of a passive ETL sensor system should be encouraged as exploratory research.

- The Integrated Refractive Effects Prediction System (IREPS) ETL climatology should be reanalyzed in a way which takes better advantage of the sparse oceanic data.

- An ETL forecasting and display capability based upon the best existing model(s) should be added to IREPS and to the Tactical Environmental Support System (TESS).

SECTION 1. INTRODUCTION

1.1 Objective. The purpose of this study is to examine the options which are now available or which could be made available to the Navy for assessing and displaying the existence or likelihood of elevated trapping layers (ETLs) and their associated ducts over a particular geographic point or area.

1.2 Report Outline. Section 2 of this report provides a somewhat detailed description of what is meant by refraction and ducting in the atmosphere. It also discusses the physical parameters which are observed or predicted in order to assess and characterize the presence or likelihood of a "trapping layer" and its associated "duct". The reader who already knows the difference between these two terms may wish to skip or only scan the first two subsections of Section 2. Similarly, a reader with refractive effects forecasting experience may wish to omit or only scan all of Section 2.

The most significant parts of this study are Sections 3 and 4 which address refractivity assessment and display options, respectively. Each of these sections begins with a short section overview or outline and concludes with a summary. The intervening description and discussion in each of these sections makes a careful distinction between central-site (Fleet Numerical Oceanography Center (FNOC)) and on-scene (for example, Battle Group) options, whenever there is a substantial difference between the two relative to assessment or display options.

Section 5 sets forth the conclusions which follow from Sections 3 and 4 and then makes specific recommendations for action. Again, these conclusions and recommendations are separated with respect to central-site and on-scene.

The last few pages provide an explanation of acronyms and abbreviations used and a list of all references cited in the text.

1.3 Terminology. Terms used in this report including all of the definitions in Section 2 are based on, and in certain cases, extracted directly from the IREPS Users Manual, Revision 2.0 (Hitney et al, 1981) and/or are consistent with the Glossary of Meteorology (Huschke, 1959).

1.4 Assistance Received. This study is based to a large extent on the authors' consultations with a number of personnel at the Naval Environmental Prediction Research Facility (NEPRF), the Naval Ocean System Center (NOSC), the Naval Postgraduate School (NPS), and the Pacific Missile Test Center (PMTC). These people gave freely of their time, their candid opinions and in some cases their yet unpublished results. Their substantial collective assistance is gratefully acknowledged and every effort has been made to cite individuals by reference or footnote where appropriate. Also, the kind assistance of Ms. Joanne May, NEPRF Librarian, was particularly helpful.

SECTION 2. DEFINITIONS AND RELEVANT PARAMETERS

2.1 Ducting and Refraction. The term Ducting in this document means the concentration of radar (or radio) waves in the lowest part of the troposphere in regions characterized by rapid vertical changes in air temperature and/or humidity. Surface Ducting means such concentration of radar waves immediately adjacent to the sea (or terrain) surface.

The refractive index, (n), of a parcel of air is defined as the ratio of the speed of propagation of an electromagnetic (EM) wave in a vacuum to that in the parcel. Since EM waves travel slightly faster in a vacuum than in air, the refractive index of an air parcel is slightly greater than unity. At the earth's surface, the numeric value of the refractive index, n, is usually between 1.000250 and 1.000400. In order to have a number that is easier to handle, the refractivity, (N), is defined as $(n - 1) \times 10^6$, such that surface values of refractivity vary between 250 and 400. Refractivity can be expressed as a function of atmospheric pressure, temperature, and humidity by the relation:

$$N = \frac{77.6P}{T} + \frac{3.73 \times 10^5 e}{T^2}$$

where:

P is atmospheric pressure in millibars,
T is temperature in Kelvin, and
e is water vapor pressure in millibars.

In a standard troposphere, both temperature and humidity decrease with altitude, such that N decreases with height at a rate of about 39 N units per 1000 meters (or 12 N units per 1000 ft). The propagation behavior of an EM wave is such that it will bend or refract toward the region of higher refractivity (lower

speed of propagation). In a standard troposphere a radar wave will refract toward the earth's surface, but with a curvature which is less than the earth's.

Therefore, in the surface layer if the air temperature increases with altitude and/or the humidity decreases with altitude at an abnormally high rate, then N will decrease with height at a higher rate than normal. If this rate of decrease is larger than 157 N units per 1000 meters (48 N units per 1000 ft), then a radar wave will refract downwards with a curvature exceeding the earth's curvature. This condition is known as a surface duct because a radar or other EM wave will repeatedly refract toward the earth's surface and then reflect or "bounce" upward from this surface. It is this repetitive downward refracting and upward reflecting within a surface duct that permits surface detections far beyond the normal radar or other EM horizon.

As a convenience in determining the occurrence of ducting, the term <u>modified refractivity</u>, <u>(M)</u>, has been developed. M is related to N and altitude h as follows:

$$M = N + 0.157\ h \text{ (h in meters), or}$$
$$M = N + 0.048\ h \text{ (h in feet).}$$

The modified refractivity takes into account the curvature of the earth in such a way that the presence of ducting can be determined from a simple inspection of plotted values of M versus altitude. Whenever M decreases with altitude within a layer, a <u>trapping layer</u> is present and an EM wave will be refracted towards the earth's surface within the layer. For example, Figure 2-01 shows N and M plotted versus altitude for a standard troposphere, and Figure 2-02 shows N and M plotted versus

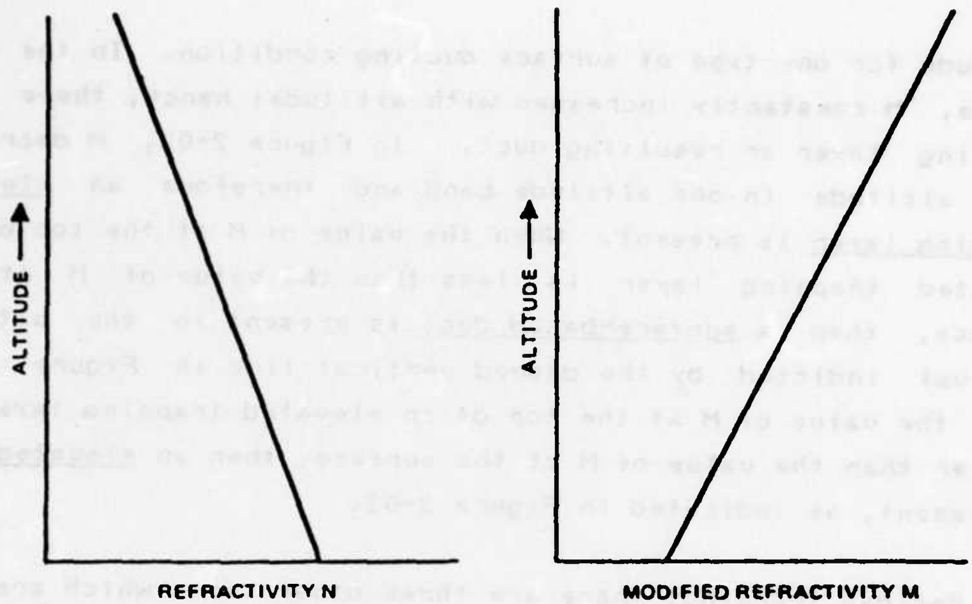

FIGURE 2-01. Refractivity N and modified refractivity M versus altitude for a standard atmosphere (Hitney et al, 1981).

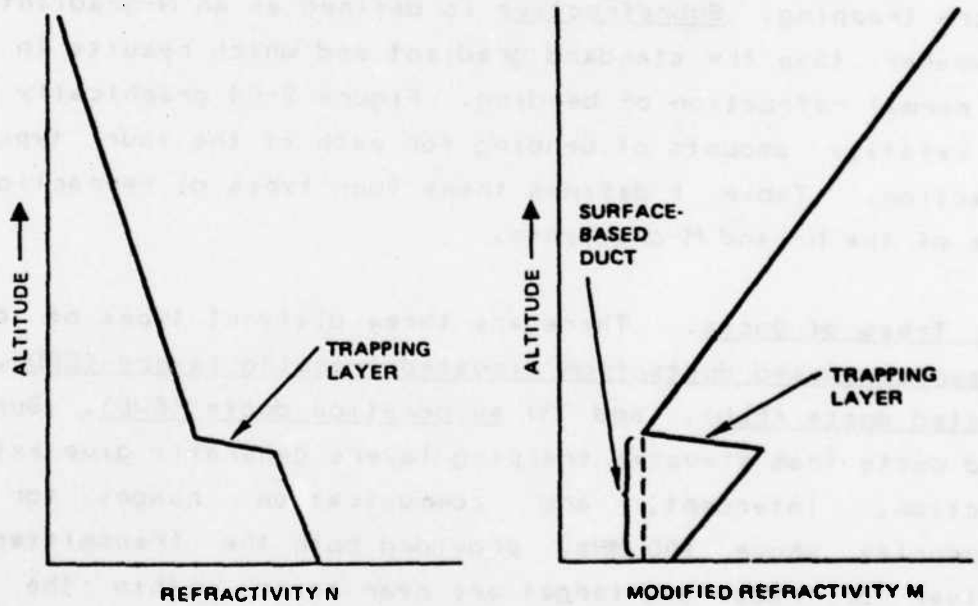

FIGURE 2-02. Refractivity N and modified refractivity M versus altitude for a surface-based duct created by an elevated trapping layer (Hitney et al, 1981).

altitude for one type of surface ducting condition. In the first figure, M constantly increases with altitude; hence, there is no trapping layer or resulting duct. In Figure 2-02, M decreases with altitude in one altitude band and therefore an elevated trapping layer is present. When the value of M at the top of the elevated trapping layer is less than the value of M at the surface, then a surface-based duct is present in the altitude interval indicted by the dashed vertical line in Figure 2-02. When the value of M at the top of an elevated trapping layer is greater than the value of M at the surface, then an elevated duct is present, as indicated in Figure 2-03.

Besides trapping, there are three other terms which are used to describe the vertical gradient or change of N and M with height; namely superrefractive, standard, and subrefractive. Superrefractive is defined as an N gradient that is stronger than the normally expected or standard gradient, *but not* strong enough to form trapping. Subrefractive is defined as an N-gradient that is weaker than the standard gradient and which results in less than normal refraction or bending. Figure 2-04 graphically shows the relative amounts of bending for each of the four types of refraction. Table 1 defines these four types of refraction in terms of the N- and M-gradients.

2.2 Types of Ducts. There are three distinct types of ducts: (1) surface-based ducts from elevated trapping layers (SBD), (2) elevated ducts (ELD), and (3) evaporation ducts (EVD). Surface-based ducts from elevated trapping layers generally give extended detection, intercept, and communication ranges for all frequencies above 100 MHz, provided both the transmitter and receiver or radar and target are near to or within the duct. Such SBD's are nearly always less than 1 km (about 3000 ft) thick, with thicknesses of up to 0.3 km (about 1000 ft) being

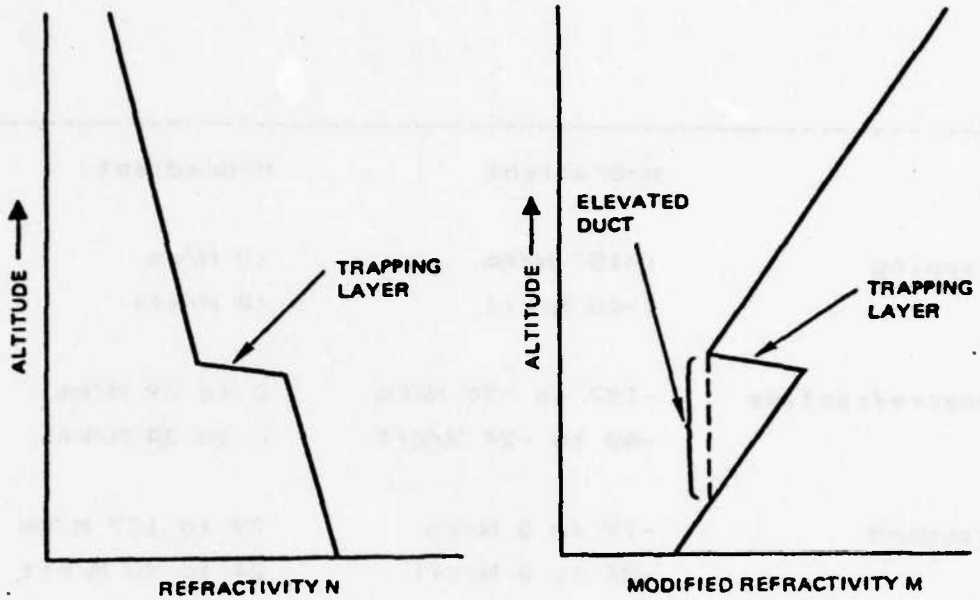

FIGURE 2-03. Refractivity N and modified refractivity M versus altitude for an elevated duct created by an elevated trapping layer (Hitney et al, 1981).

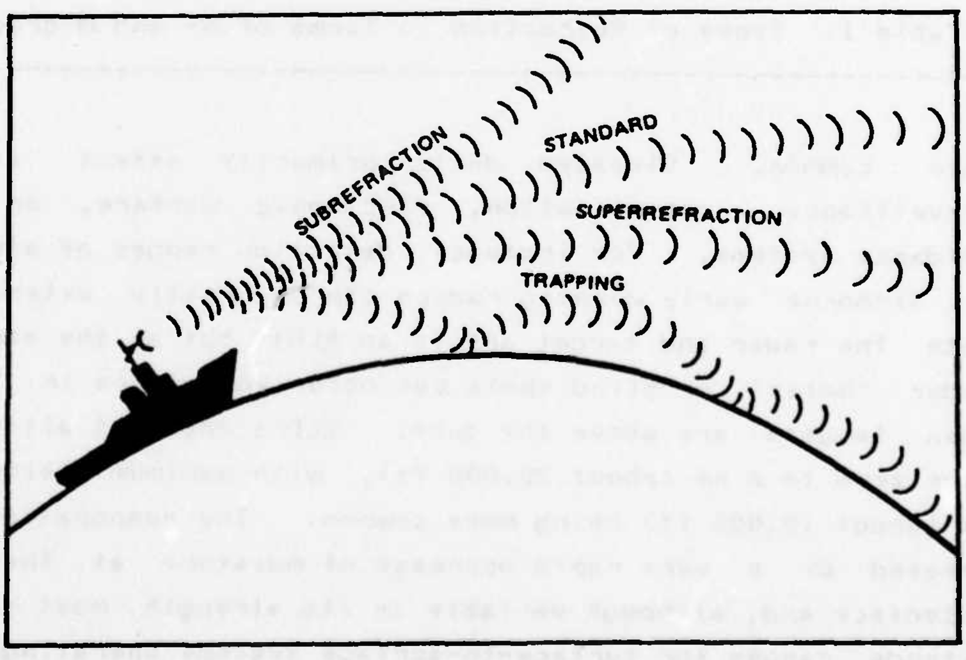

FIGURE 2-04. Relative bending for the four types of refraction (Hitney et al, 1981).

	N-Gradient	M-Gradient
Trapping	<-157 N/Km <-48 N/Kft	<0 M/Km <0 M/Kft
Superrefractive	-157 to -79 N/Km -48 to -24 N/Kft	0 to 79 M/Km 0 to 24 M/Kft
Standard	-79 to 0 N/Km -24 to 0 N/Kft	79 to 157 M/Km 24 to 48 M/Kft
Subrefractive	>0 N/Km >0 N/Kft	>157 M/Km >48 M/Kft

Table 1. Types of Refraction in Terms of N- and M-gradients

more common. Elevated ducts primarily affect air-to-air surveillance, communication, electronic warfare, or weapons guidance systems. For instance, detection ranges of air targets by airborne early warning radars can be greatly extended when both the radar and target are in an ELD; but at the same time, radar "holes" or blind spots can occur for radars in the duct when targets are above the duct. ELD's occur at altitudes of near zero to 6 km (about 20,000 ft), with maximum altitudes of 3 km (about 10,000 ft) being more common. The evaporation duct is created by a very rapid decrease of moisture at the air/sea interface and, although variable in its strength, most frequently extends ranges for surface-to-surface systems operating above a frequency of 3 GHz. The EVD and its effects are not part of this

study and will, therefore, not be discussed further.

2.3 Observable Parameters. The presence of ducting requires a trapping layer which in turn requires a negative M-gradient (see Table 1). To assess ducting or trapping requires: (1) observing the phenomenon itself, with a radar display or radio receiver for example, (2) measuring (or deriving from other measurements) the physical variables which will permit computation of the determining M-gradient, or (3) inferring the likelihood of ducting through the observation or measurement of phenomenon or parameters which usually attend this condition. Categories (2) and (3) are discussed below.

2.3.1 Quantitatively Observed Parameters. As previously discussed in subsection 1.2.1, refractivity (N) (or modified refractivity (M)) is a function of atmospheric pressure, temperature and moisture. The relative significance of these three atmospheric terms is illustrated in Table 2.

Temperature T (°C)	Pressure P (mb)	Vapor Pressure e (mb)	$\frac{\partial N}{\partial P}$	$\frac{\partial N}{\partial T}$	$\frac{\partial N}{\partial e}$
27.0	1013.25 (sea level)	30	0.3	-1.7	4.1
0.0	767.0 (∿7500 ft-pressure height)	5	0.3	-1.0	5.0

TABLE 2. Expected N Unit Changes for a Unit Change in Selected Values of P, T, and e (Purves, 1974).

All three variables (pressure, temperature and moisture) can be measured by the standard balloon-borne radiosonde as it ascends through the atmosphere. Values of these variables are transmitted by radio to a receiver at the launching ship or station during the balloon's ascent.

The reader is reminded that radiosondes require radio transmissions to capture the sensor data; and, depending on the altitude attained and the velocity of the winds encountered during ascent, a sonde will travel up to several tens of kilometers from the launch site.

An excellent alternative to the radiosonde is the AN/AMH-3 Airborne Microwave Refractometer (AMR) developed by NAVAIR, now in production and scheduled for deployment in E2C aircraft in 1984. The AMR measures refractivity directly and records it on magnetic cassette tape for post-flight processing. This system has the advantage of radio silence but the concomitant disadvantage of having to wait for aircraft recovery before shipboard or shore station use can be made of the data (unless of course a decision is made to down-link the recorded information to a ship or ground station).

Other observational methods may appear or be developed in the future. For example, Gossard et al (1980) concluded that an upward looking FM/CW radar operating in the non-doppler mode provided a better estimate of the height and persistency of elevated trapping layers than thrice daily rawinsondes because such layers undulate and the refractive index distribution is often transient and patchy. Richter and Jensen (1976) demonstrated the ability of both FM-CW radar and the acoustic echo sounder to observe atmospheric micro structures (for example inversion base height). They point out that since the FM-CW radar is most sensitive to moisture fluctuations while the acoustic sounder senses temperature fluctuations the two systems produce complimentary information. Smith (1974) discusses prior work on the passive detection of ducting layers by analysis of low-elevation angle navigation satellite reception data and

shows that both standard and anomalous refractive profiles are recoverable in a computer simulation. In related work, however, Anderson (1980) concludes that although moderate success was achieved in inferring refractive structure from observations of low-angle, satellite-to-ground, radio frequency transmissions, operationally significant data could not be extracted reliably.

<u>2.3.2 Qualitatively Observed Parameters</u>. A trapping layer involves a sharp negative moisture gradient and/or a sharp positive temperature gradient with increasing altitude (decreasing atmospheric pressure). It involves a substantial change in atmospheric density within a small vertical distance. In other words, an "inversion situation" which is often recognizable by a near-casual observer. The west coast (east ocean) stratus is capped by an inversion. The subtropical, near-equatorial tradewind cumulus is capped by an inversion. A warm front is capped by an inversion and so is the haze or smog layer observed from high hills. The haze restricting visibility on an otherwise clear day is an inversion phenomenon. High pressure and calm or light winds in middle latitudes implies a subsidence inversion which may or may not be evident in ways just discussed.

Most of the above phenomena can be seen in standard cloud imagery and inferences about the likelihood of ducting can thus be made over very large geographic areas. Several interesting correlations between cloud imagery, inversions and ducting are discussed by Purves (1974) and by Helvey and Rosenthal (1983).

<u>The mere presence or absence of an inversion, however, does not mean trapping</u>. The inversion must be strong enough - the M- or N-gradient large enough - to cause ducting. Subjective observations are better at telling us where trapping <u>will not</u> occur than where it <u>will</u> occur.

2.4 Predictable Parameters. Many parameters which can be easily observed, cloud type for example, are not easily forecast - at least not by modern computer prediction models. Other parameters, precipitable moisture in a column of air for example, are much more easily modeled than observed.

2.4.1 Objective Forecast Variables. In this discussion an objective forecast is one obtained from a forecast model - most typically a numerical prediction model run on a computer (large or small) and with which various atmospheric variables are computed at discrete future times for discrete points on a one, two or three dimensional grid. For ETL purposes we need consider only the mass or density variables - pressure, temperature and moisture. All three variables in one form or another are predicted by or directly derivable from the output of most forecast models now in use or in final stages of development. One model may forecast specific humidity another mixing ratio, or one may forecast at points on a constant pressure surface rather than at a constant height above sea level; but with interpolation and/or simple calculations the terms required for ETL applications can be obtained.

But all models are by no means equal in precision, resolution, speed and computer resource requirements. Forecasts for only a few points in the vertical and many points in the horizontal may be good for one application, but another purpose may be better served by high vertical resolution and little or no horizontal resolution. One model may be highly dependent on a second model to provide initial condition or time dependent input - horizontal advection (wind) or subsidence (vertical velocity) terms for example. Another may rely on an empirical constant. Such tradeoffs and interrelationships are discussed in more

detail in Section 3.

Statistical analysis of forecast model output provides a logical extension to objective forecasting as discussed to this point. Such analysis when related to a non-predicted (or less skillfully predicted) variable may provide highly useful information. For example, lacking a highly resolved vertical profile of M, what is the statistical correlation between (1) a forecast gradient of M greater than 0 but less than X between one level and its distant neighbor, and (2) the occurrence of a trapping layer (M less than 0) in between the two levels.

2.4.2 Subjective Forecast Variables. Objective forecasts of the variables controlling refractivity may not be available for the time and place required. In such cases the environmental forecaster and in turn the tactical commander must rely on subjective aids. Is there a general relationship between the present or forecast large scale synoptic situation and ducting in the area of interest? Does the cloud pattern favor elevated or surface based ducts? If the present situation is anomalous for the time and place in question, is a change toward the norm likely? Subjective forecast parameters are pretty much limited to qualitative terms, such as: duct-likely or duct-unlikely; near-surface based or well elevated; and persistent or short-lived.

SECTION 3. ASSESSMENT OPTIONS

<u>3.1 Assessment Overview</u>. This section considers ways which are in place now or likely to be available soon to assess the refractivity at a particular point or over a particular area at a particular time and to assess how this refractivity may vary with respect to time during a specified period of time. A simple approach is to sample or observe the situation at or over the scene and then use persistence for the length of time required. More complex approaches are concerned with forecasting the spatial and/or time variability of refractivity. Such forecasting can be done on-scene for example by an aircraft carrier or battle group staff meteorologist, it can be done at one of several far-from-scene, area-support activities such as the Naval Oceanography Centers (OCEANCENs) in Pearl Harbor or Norfolk, or it can be done at FNOC, the Navy's central-site for operational, numerical prediction.

After a discussion of observations and persistence in subsection 3.2, which is applicable to any activity with access to recent on-scene measurements, this section reviews in subsection 3.3 the use of climatology as an assessment method. Then the various central-site ETL assessment options are discussed in subsection 3.4. These are followed by a summary of on-scene forecasting in subsection 3.5. Far-from-scene assessment is not discussed since the options available to OCEANCENs, to Oceanography Command Facilities and Detachments and the units and activities which they support, and to environmental forecasters on major shore staffs are highly situation and location dependent. The far-from-scene forecaster will use a combination of on-scene and central-site options which will depend on his/her in-house computer assets and access to on-scene data and FNOC products.

3.2 <u>Observations and Persistence</u>. An observation taken at the point of concern with a properly calibrated and functioning radiosonde or airborne refractometer is obviously the best assessment possible for that place and time. It is also the best possible nowcast for the "vicinity" of that place and for a "short" period of time thereafter. It is not so easy, however, to decide when the horizontal homogeneity assumption breaks down and "vicinity" becomes "too far", or when the time conservative assumption breaks down and "short" becomes "too long". Most experienced forecasters would say persistence is generally valid for a few hundred miles and a few hours. When pinned down further they are apt to say 100 to 500 miles (but not across a discontinuity, such as a front or coastline!) and 3 to 12 hours.

Provided they are not rendered "old" by transmission delays, the on-scene radiosonde or refractometer measurements of vertical structure are also useful to the central-site or other C^2 support activity ashore where the observations can be used as input to forecast models such as NOLAPS (see subsection 3.4.1.3) or effects assessment systems such as IREPS.

Additionally, a set of near simultaneous on-scene and near-scene radiosondes can be assimilated by the central-site and used to analyze the atmospheres "recent" horizontal variability and to forecast its future vertical structure and horizontal variability. <u>An important point, however</u>, the radiosonde observation, with its temperature and moisture values at several "mandatory" and "significant" levels, looses most of this vertical structure definition when the observation is assimilated by the central-site analysis scheme and reduced to values at a few fixed levels on a vertical coordinate system. For example, the current version of NOGAPS (see subsection 3.4.1.1) has nine

analyzed levels between the surface and about 20 km (66,000 ft). Since only three of these nine levels are below about 4 km (13,000 ft), there are only four point values in the vertical (including the surface) available to describe the lower troposphere where most trapping layers are found. This is why, unlike the "raw" soundings themselves, the FNOC analyzed fields cannot be used to directly assess ETLs and their associated ducts. (This point will be illustrated in subsection 3.4.1.3.)

In addition to the radiosonde and refractometer, there are other on-scene observation methods which could be used. Perhaps the best is the PPI radar display which can positively "observe" a duct while tracking own-force ships and aircraft at various known ranges and altitudes. Higher frequency (normally line-of-sight) radio reception over known extended ranges can also serve as an "observer". As discussed in an earlier paragraph, cloud imagery obtained with standard, shipboard environmental satellite receiving equipment (the AN/SMQ-6, 10 or 11) can also be used to infer anomalous propagation conditions.

But, until some reliable continuous and/or passive ETL monitoring system such as one of those discussed at the end of subsection 2.3.1 is developed, the best possible assessment strategy will be the launching of a radiosonde or a refractometer equipped aircraft every six hours through or into each 1,000 square mile area of immediate Fleet interest where the risk of anomalous propagation is high. This strategy is generally followed today, but it obviously breaks down when radio silence precludes radiosonde transmitters, when the time or area of interest is too distant, or when it is not possible to transmit the observation to the central-site and/or interested C^2 activity ashore in a timely manner. The options available in such cases are discussed in the balance of this section.

3.3 Climatology. The normal or average state of the environment for a particular place, season and local time of day has always been of great value as a forecasting aid. The longer the forecast time, the more any forecast will approach climatological values. Even in shorter-time-range forecasting it is reasonable to routinely relax persistence toward climatology. Given no observations and no other relevant information in near-time or near-space, climatology (if known) should be the forecast. "If known" is an important qualifier, however. Inadequate climatology applied to a situation may be worse than no forecast at all. It may well be better to prepare for any reasonable condition than for a single condition if that single condition derives from a climatology stretched to far in space or carried to unsupported significant figures.

The discussion above is particularly relevant when considering ETL's - an upper air (non-surface) phenomenon which depends on a complex combination of negative moisture gradient and/or positive temperature gradient with increasing altitude such that M is less than zero.

The only climatology which one might consider an ETL climatology for Navy use is the so called IREPS (Integrated Refractive Effects Prediction System) climatology. The IREPS climatology is available in magnetic form for Hewlett-Packard (HP) 9845 systems and at FNOC, and is available in hard-copy publication form as NOSC TD 573 (Patterson, 1982). The IREPS climatology contains both surface data relating to evaporation ducts and upper air data relating to ETL's. It is based on ten years (1970-1979) of ship surface observation compiled by the Naval Oceanography Command Detachment, Asheville, North Carolina and on five non-contiguous years (between 1966 and 1974) of

worldwide coastal, island and fixed-location station ship radiosonde reports compiled by GTE Sylvania, Inc. (Ortenberger et al, 1977). Data (and henceforth we will discuss ETL-related upper air data only) is provided in yearly and seasonal sets (with day, night, and 24 hour subsets) of frequencies of occurrence and average values for 216 Marsden (10 x 10 degree) squares (MS) covering Northern Hemisphere coastal and open ocean, and Southern Hemisphere coastal areas. Figure 3-01, for example, is the data for MS 78, which is in the North Atlantic.

There is a serious inherent problem with the GTE data used for the IREPS climatology and that is the extremely sparse data over open ocean areas. Figure 3-02 which shows the GTE five year radiosonde data coverage contains a few stations which submitted as little as three percent of the 3,650 possible soundings (5 yrs x 365 days/year x 2 soundings/day). Many, particularly in the Southern Hemisphere, reported as little as fifty percent of the time. At some locations this meant only day or night was really being measured, since only 12Z or 00Z observations were routinely taken.

Another problem arises from considering how the small amount of data available has been used. When preparing the IREPS climatology in MS format, the data from the reporting station nearest to the center of a square was assigned to that square. In one case in the subtropical North Atlantic this meant assigning data from over eight degrees south and twelve degrees east to MS 76 and from ten degrees north and three degrees west to MS 77, an adjacent square. In another case in the equatorial North Pacific, data from over fourteen degrees north (but at the same longitude) was assigned to MS 16. Figure 3-01 illustrates the same sort of problem (an eight/seven degree lat/long difference). It appears better use of the limited data could have

IREPS REV 2.1 HISTORICAL PROPAGATION CONDITIONS SUMMARY

Specified location: 25 00 N 55 00 W (*) INDICATES INSUFFICIENT DATA
Radiosonde source : 78861 17 07 N 61 46 W
Radiosonde station height: 33 Feet
Surface obs source: MS78 25 00 N 55 00 W

PERCENT OCCURRENCE OF ENHANCED SURFACE-TO-SURFACE RADAR/ESM/COM RANGES:

FREQUENCY	YEARLY			JAN-MAR			APR-JUN			JUL-SEP			OCT-DEC		
	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n
100 MHz	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1 GHz	31	9	20	25	8	16	33	9	21	37	10	24	27	8	18
3 GHz	42	15	29	37	15	26	43	14	29	49	17	33	41	17	29
6 GHz	76	56	66	71	54	63	74	49	61	81	61	71	77	61	69
10 GHz	92	86	89	90	85	88	91	83	87	94	88	91	93	89	91
20 GHz	97	94	95	96	93	95	96	93	95	98	95	96	97	95	95

SURFACE BASED DUCT SUMMARY:

PARAMETER	YEARLY			JAN-MAR			APR-JUN			JUL-SEP			OCT-DEC		
	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n
Percent occurrence	2	0	1	1	0	1	1	0	1	2	0	1	3	0	2
AVG thickness Kft			.33			.28			.45			.26			.34
AVG trap freq GHz			.78			1.0			.81			.66			.66
AVG lyr grd -N/Kft			200			353			200			82			163

ELEVATED DUCT SUMMARY:

PARAMETER	YEARLY			JAN-MAR			APR-JUN			JUL-SEP			OCT-DEC		
	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n
Percent occurrence	44	0	22	49	0	25	41	0	21	42	0	21	42	0	21
AVG top ht Kft			6.5			6.9			6.4			6.0			6.8
AVG thickness Kft			.40			.41			.38			.40			.42
AVG trap freq GHz			.43			.44			.48			.42			.37
AVG lyr grd -N/Kft			60			57			58			62			61
AVG lyr base Kft			6.2			6.6			6.1			5.7			6.5

EVAPORATION DUCT HISTOGRAM IN PERCENT OCCURRENCE:

PERCENT OCCURRENCE	YEARLY			JAN-MAR			APR-JUN			JUL-SEP			OCT-DEC		
	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n
0 to 10 Feet	1	1	1	2	2	2	2	2	2	1	1	1	1	1	1
10 to 20 Feet	2	4	3	2	5	3	2	5	4	1	4	3	2	4	3
20 to 30 Feet	4	8	6	5	8	7	5	10	7	4	7	6	4	7	5
30 to 40 Feet	7	12	9	8	13	10	7	14	11	5	9	7	6	10	8
40 to 50 Feet	10	18	14	12	18	15	10	20	15	8	17	13	11	17	14
50 to 60 Feet	13	19	16	13	18	15	12	18	15	11	21	16	14	19	16
60 to 70 Feet	12	13	13	12	13	13	11	11	11	11	14	12	13	15	14
70 to 80 Feet	10	8	9	10	8	9	8	6	7	10	9	9	11	10	10
80 to 90 Feet	7	4	6	7	5	6	6	3	4	7	4	5	8	5	7
90 to 100 Feet	5	2	4	5	2	4	4	2	3	5	2	4	5	3	4
above 100 Feet	30	9	19	24	8	16	32	9	21	37	10	23	26	8	17
Mean height Feet	91	60	76	82	58	70	93	58	76	101	63	82	87	62	74

GENERAL METEOROLOGY SUMMARY:

PARAMETER	YEARLY			JAN-MAR			APR-JUN			JUL-SEP			OCT-DEC		
	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n	day	nit	d&n
% occur EL&SB dcts			1			1			1			1			1
% occur 2+ EL dcts			11			13			10			10			1.
AVG station N			373			363			372			381			376
AVG station -N/Kft			18			16			18			19			18
AVG sfc wind Kts	11	10	11	13	12	12	11	9.4	10	10	9.3	10	12	11	11

FIGURE 3-01. Sample page from IREPS Climatology (Patterson, 1982).

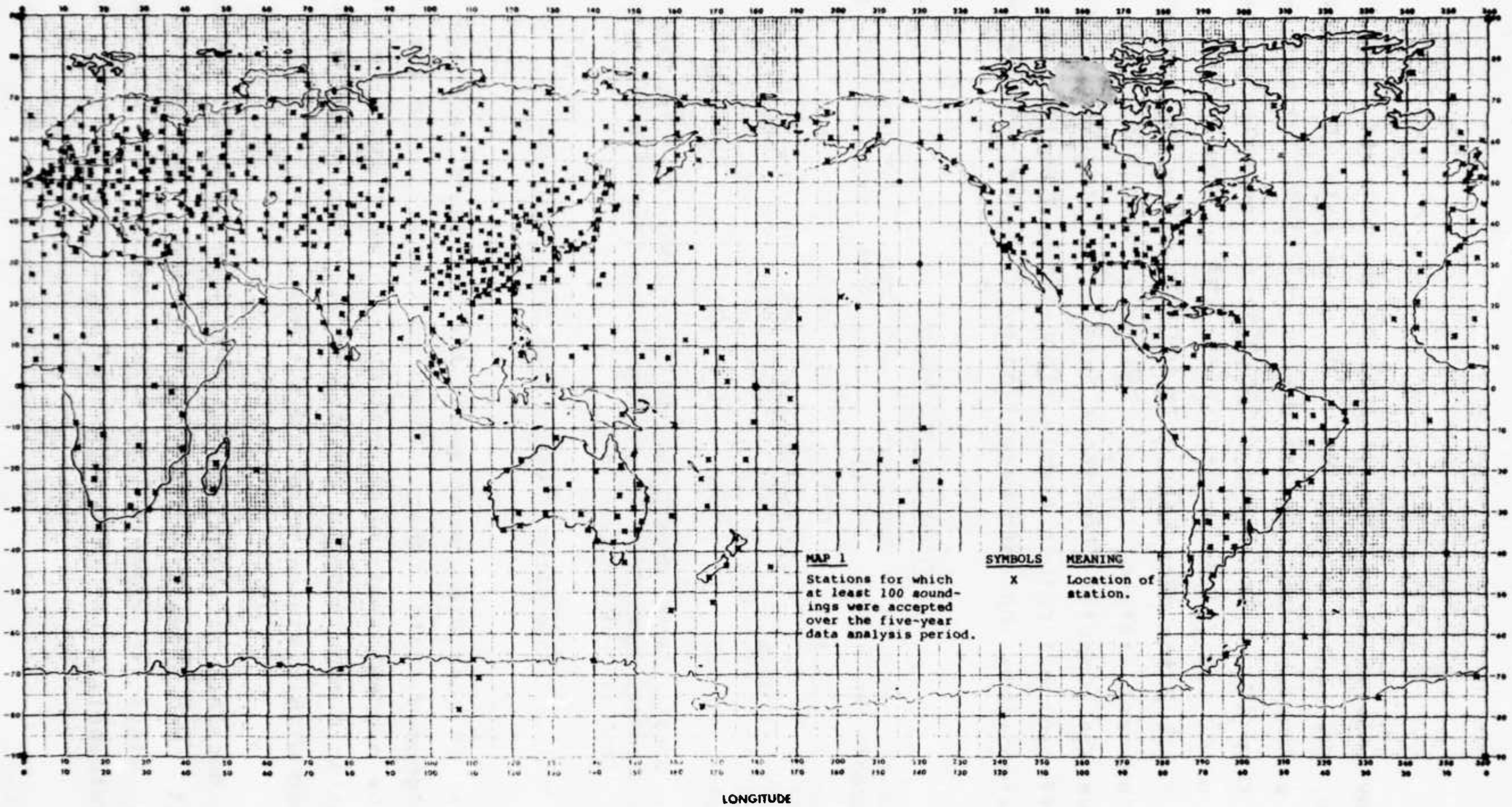

FIGURE 3-02. Radiosonde data distribution in IREPS Climatology (Ortenburger et al, 1977).

been made by interpolating from several of the nearest reporting stations to the center of each MS. To illustrate this point certain key parameters were extracted from the IREPS climatology for station ship 4TV. This ship ("VICTOR") is conveniently near the center of MS 128 in the North Pacific (34 vs 35N and 164 vs 165E). In Table 3 the extracted ship VICTOR values are compared with the "nearest station" (Marcus Island at 24N 154E) and an ensemble average computed from three "near sets" extracted with slightly different but rather simple algorithms. However, none of the three algorithms included weighting by distance from center.

YEARLY DAY AND NIGHT

	Percent Occurrence	Avg Top Ht. (kft)	Avg Thick. (kft)	Avg Trap Freq (GHz)	Avg Layer Grd (-N/kft)	Avg Layer Base (kft)
SHIP 4YV	22	5.3	.44	.40	64	5.0
MARCUS IS.	34	5.7	.51	.30	59	5.3
SET A AVG	19	5.6	.37	.86	61	5.3
SET B AVG	23	5.2	.40	.82	66	5.0
SET C AVG	25	5.3	.42	.72	65	5.0

NOTE: Set A: Sendai, Japan; Urup, USSR; Marcus Is.; Wake Is.; and Shemya, Alaska
Set B: Sendai, Japan; Wake Is.; Midway Is.; and Ostrov Beringa, USSR
Set C: Same as B plus Marcus Is.

Table 3. Ship Victor Elevated Duct Data Comparisons

Of the 18 possible comparisons, the ensemble average is closer to "ground truth" (ship VICTOR) 13 times; there are two ties and the nearest station is best only three times. In this and two similar comparisons in the Atlantic, results would have been improved with distance weighted averages.

Since ducting strongly favors certain geographic areas - those east and equatorward of the large semi-permanent subtropical highs for example (see Figure 3-03) - it is probably unwise to extrapolate far into or out of such areas without some

compensating adjustments from other quadrants as just discussed. For this reason a recommendation is made in Section 5 to have the IREPS surface based and elevated duct summaries recomputed.

A third problem concerning climatology for ETL applications is that the IREPS climatology is conveniently machine readable and displayable only with HP 9845 systems. A seasonal ETL climatology on one of FNOC's primary computer systems in a plan view, contour map form which is suitable for transmission and display on Naval Environmental Display Station (NEDS) or C^2 display devices would be highly useful. Such a climatology could serve as an ETL forecasting and briefing aid where and when broad area predictions and briefings are desired. It could be constructed by analyzing the present, or preferably the recomputed, IREPS climatology. Alternatively, an elevated duct (but not surface-based duct) "plan view ETL climatology" could be assembled by digitizing some or all of the 13 elevated duct world contour maps in Miller et al, 1979. Figure 3-03 is an example of these maps which are mostly seasonal in composition and which, since they are derived from the very same Five Year Data, should be consistent with the IREPS climatology. Creation of a digitized, contoured ETL climatology is also recommended in Section 5.

<u>3.4 Central-site Forecasting</u>. As indicated previously, central-site is synonymous with Fleet Numerical Oceanography Center (FNOC), Monterey, California where all of the Navy's large computer prediction models are run; either on a routine production basis to prepare scheduled, multi-subscriber products, or on a when-needed basis in response to fleet unit or area oceanography center special requests for tailored product support.

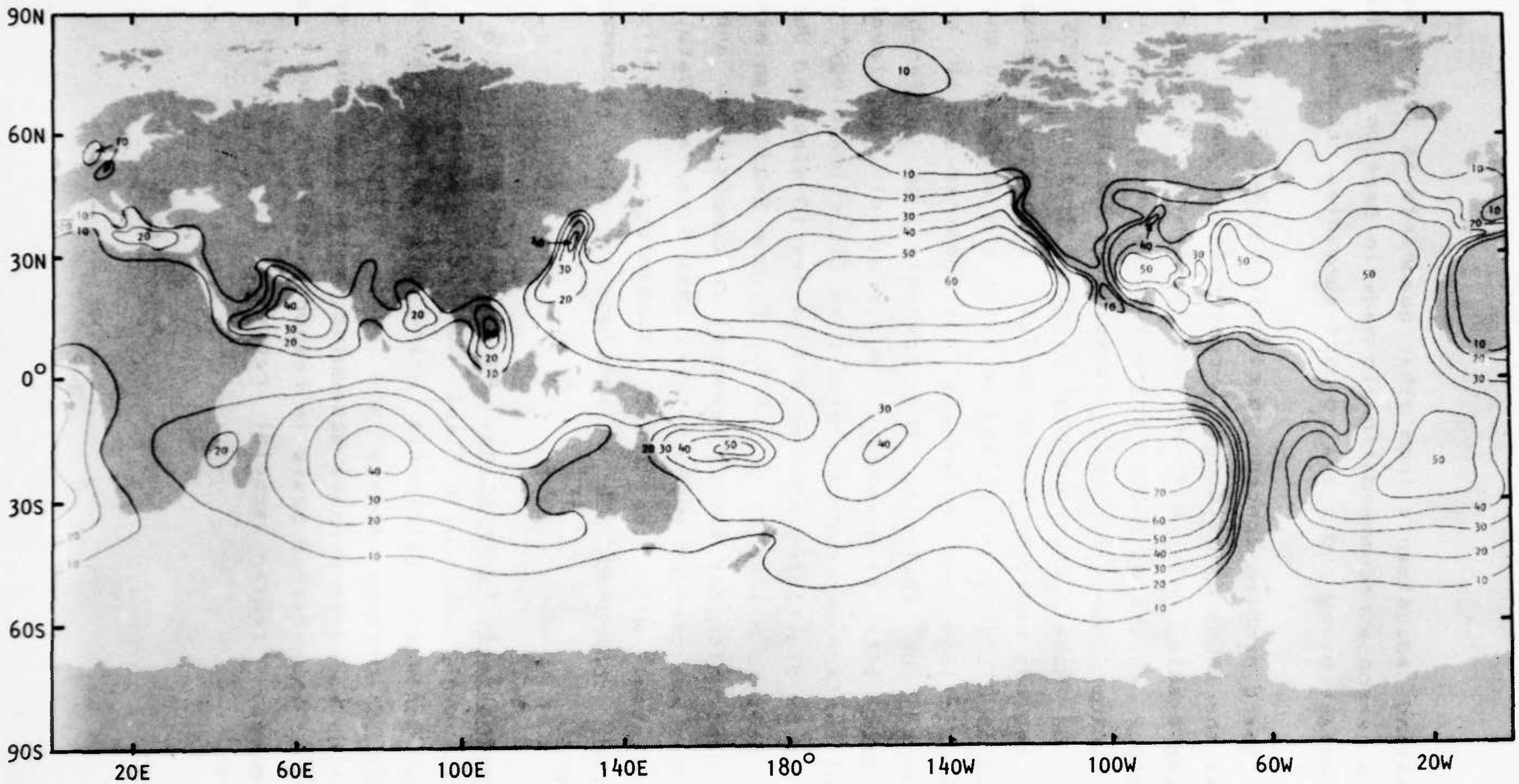

FIGURE 3-03. Annual percent occurrence of elevated ducts (Miller, et al., 1979).

3.4.1 Central-site Numerical Prediction. For this discussion a numerical prediction is the result obtained from a deterministic, physical model of (at least) the lower troposphere. Such models at FNOC are used within prediction "systems" which include appropriate software for input data analysis and (or at least) for model initialization with a reasonable estimate of the "recent" atmospheric state so that the "future" state can be predicted by the forecast model. For ETL forecasting any model must include certain formulations, parameterizations or diagnostics concerning planetary boundary layer (PBL) processes. Such processes are of primary importance when one wants to determine the presence or absence of surface based and elevated ducts. Very fast, high capacity central-site computers permit the running of resource intensive two and three dimensional models which can cover all or large areas of the globe. The less sophisticated prediction models which could be run on less powerful, on-scene, shipboard computers will be discussed in subsection 3.5.

3.4.1.1 The Global Model (NOGAPS). FNOC's global predictions are produced by the Navy Operational Global Prediction System (NOGAPS). This system was described by Rosmond (1981) and for our purposes remains unchanged except for a late 1983 shift from six to nine fixed levels in the vertical. For ETL prediction purposes this is significant since the models PBL, which floats (gets shallower and deeper) within the lower fixed level, is now constrained to a maximum thickness of about 155 mb (about 1,500 m/4,900 ft). Since the approximate upper thickness limit of the well-mixed PBL is 2,000 m/6,600 ft and since the top of the trade wind inversion can often be in excess of 3,000 m/9,800 ft, the NOGAPS PBL depth constraint detracts from its usefulness as an ETL forecasting tool. However, where and when ETL elevations greater than about 4,500 ft are infrequent and unimportant, the

NOGAPS PBL strength (the magnitudes of the across-the-top-of-the-layer temperature and moisture discontinuities) and its thickness should be able to provide an excellent estimate of the likelihood and elevation of an ETL. To make such an assessment would require applying Model Output Statistics (MOS) techniques (see subsection 3.4.2) to the NOGAPS output. A recommendation to explore such an approach is made in Section 5.

<u>3.4.1.2 The Regional Model (NORAPS)</u>. At this writing, the Navy does not have a fully operational regional prediction capability, but the Naval Environmental Prediction Research Facility (NEPRF) has developed the Naval Operational Regional Atmospheric Prediction System (NORAPS) which will undergo extensive operational evaluation (OPEVAL) in early 1984. NORAPS provides shorter range, higher horizontal and vertical resolution atmospheric predictions than NOGAPS, but for a limited square or rectangular domain. These areas are typically on the order of 7,500 km/4,500 nm on a side. The four regions to be regularly run for OPEVAL purposes are Europe and the Mediterranean, the Eastern U.S. and Western Atlantic, the Central and Eastern North Pacific, and the Western Pacific.

NORAPS as described by Hodur (1982) was recently substantially upgraded for our purposes by the addition of an improved long and short wave radiation package and by a reformulation of its PBL which permits the top of the PBL (unlike NOGAPS) to float freely within several levels. NORAPS thereby imposes no upper constraint on likely ETL altitude. NORAPS output could thus be used to assess not only the lower (stratus type) inversion height and strength but also the higher (trade wind cumulus type) inversion height and strength. That would permit the mapping and display of ETL information over wide geographic areas of high fleet interest since that is where

NORAPS is/will be routinely focused.

Accordingly, Section 5 recommends a thorough evaluation of NORAPS output for ETL assessment applications. As in NOGAPS, the MOS approach is indicated - particularly since cross-PBL jumps in temperature and moisture are not among NORAPS's routinely computed and saved fields and ETL likelihood may have to be statistically determined from less definitive model output.

<u>3.4.1.3 The Local Model (NOLAPS)</u>. Also running in a psuedo-operational mode at FNOC, and also scheduled for more formal OPEVAL in 1984, is the Navy Operational Local Atmospheric Prediction System (NOLAPS). Its domain can be either a single point or an array of several points along a line or within an area of perhaps 500 km/300 nm on a side. Unlike NOGAPS which has three vertical levels within the lower 4 km/13,000 ft of the atmosphere and NORAPS with only about six, NOLAPS has 55 points in the vertical with which to describe the ETL-determining refractively structure.

The heart of NOLAPS is the one dimensional, second-moment closure model developed at NEPRF specifically for marine atmospheric boundary layer prediction. It is often referred to simply as the "closure model". The model, some results and some possible applications are described by Burk and Thompson (1982). The input to closure can be an on-scene (local) sounding together with a few on-scene observations such as sea surface temperature or estimates thereof extracted from large-scale model output; or, NOLAPS can be initialized completely with large-scale model output as described by Burk and Thompson.

In the latter case, NOLAPS uses the NOGAPS analyses and forecast fields to derive synoptic tendency terms which are added

as external forcing functions to the closure model equations. Thus, three dimensional advective information from the global model is coupled with the one dimensional local model. Since a local, single-point 24 hour forecast can be done in less than one-quarter minute on the FNOC Cyber 170/175 computer, it is feasible, as indicated above, to prepare an array of NOLAPS point forecasts which can show the ETL variability along a track or over a geographic area.

Figures 3-04 and 3-05[1] show vertical cross-sections of modified refractivity (M) derived from a set of initial conditions as extracted from NOGAPS fields and the resultant 24 hour forecasts from NOLAPS. The cross-sections are along a 650 km/350 nm generally east-west line in the eastern Mediterranean near Cyprus. The cross sections are defined by five NOLAPS points: one each at the left and right margins, one in the center and one each to the left and right of center. The first thing to note is the lack of detail in the initial conditions (Figure 3-04). There is no hint of any sort of strong inversion - not because it did not exist, but because the three available NOGAPS levels in the vertical were too few to describe it. It is the large-scale forcing within NOLAPS and the very high vertical resolution of the closure model which permit the development and evolution of the realistic refractive structure in the 24 hour forecast (Figure 3-05). It is also interesting to note the horizontal variability which can be seen in a multi-point cross-section.

Another example of NOLAPS output is shown in Figure 4-05 and

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[1] Figures 3-04 and 3-05 as well as Figures 4-05 and 4-06 in the next section were provided by Dr. S. D. Burk of NEPRF.

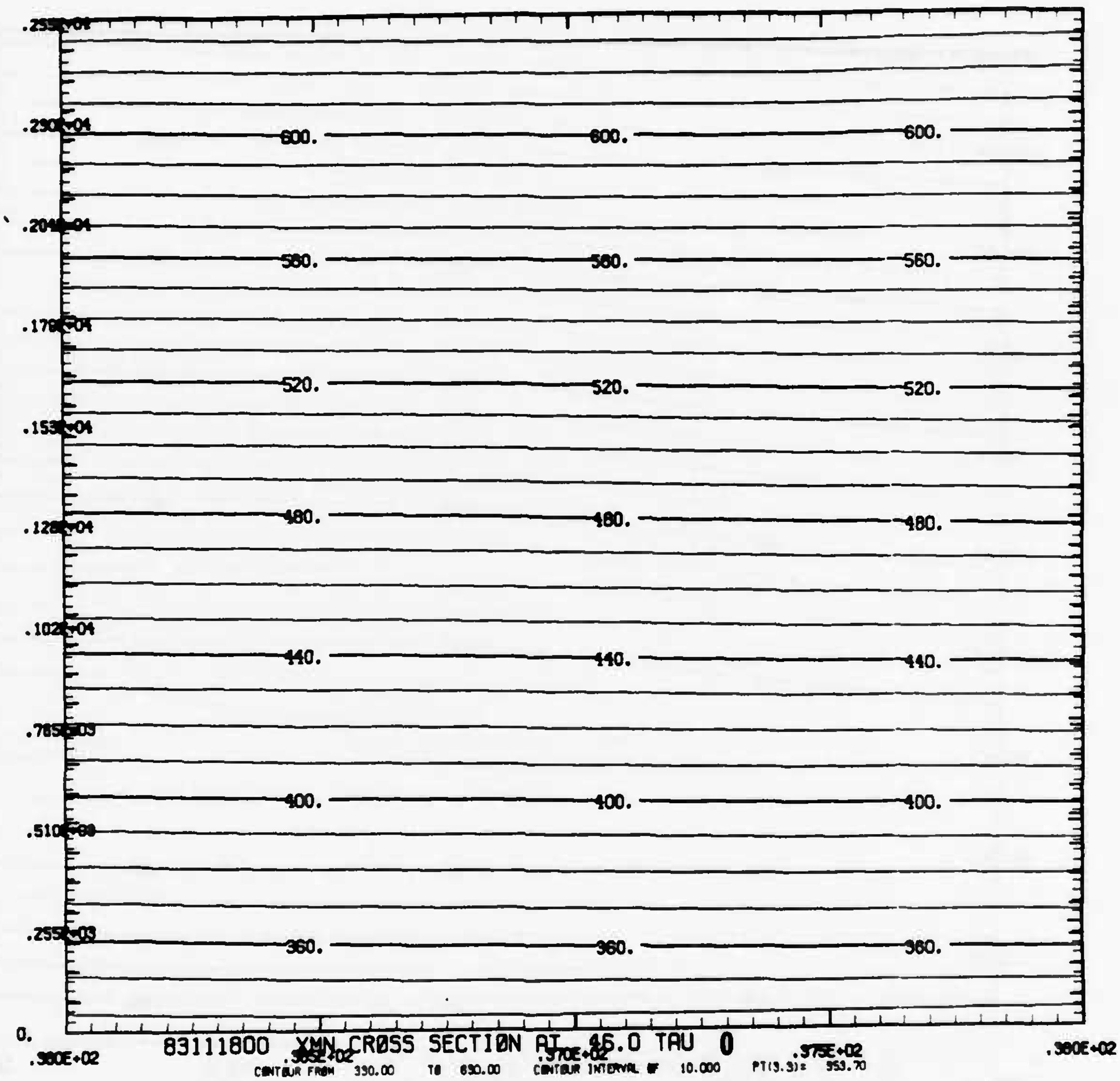

FIGURE 3-04. Vertical cross-section of NOLAPS initial modified refractivity (M) conditions derived from NOGAPS fields. (Engineering notation is used for height (meters) and longitude (east). For example, maximum ordinate value (.255E+04) is 2,550 meters.)

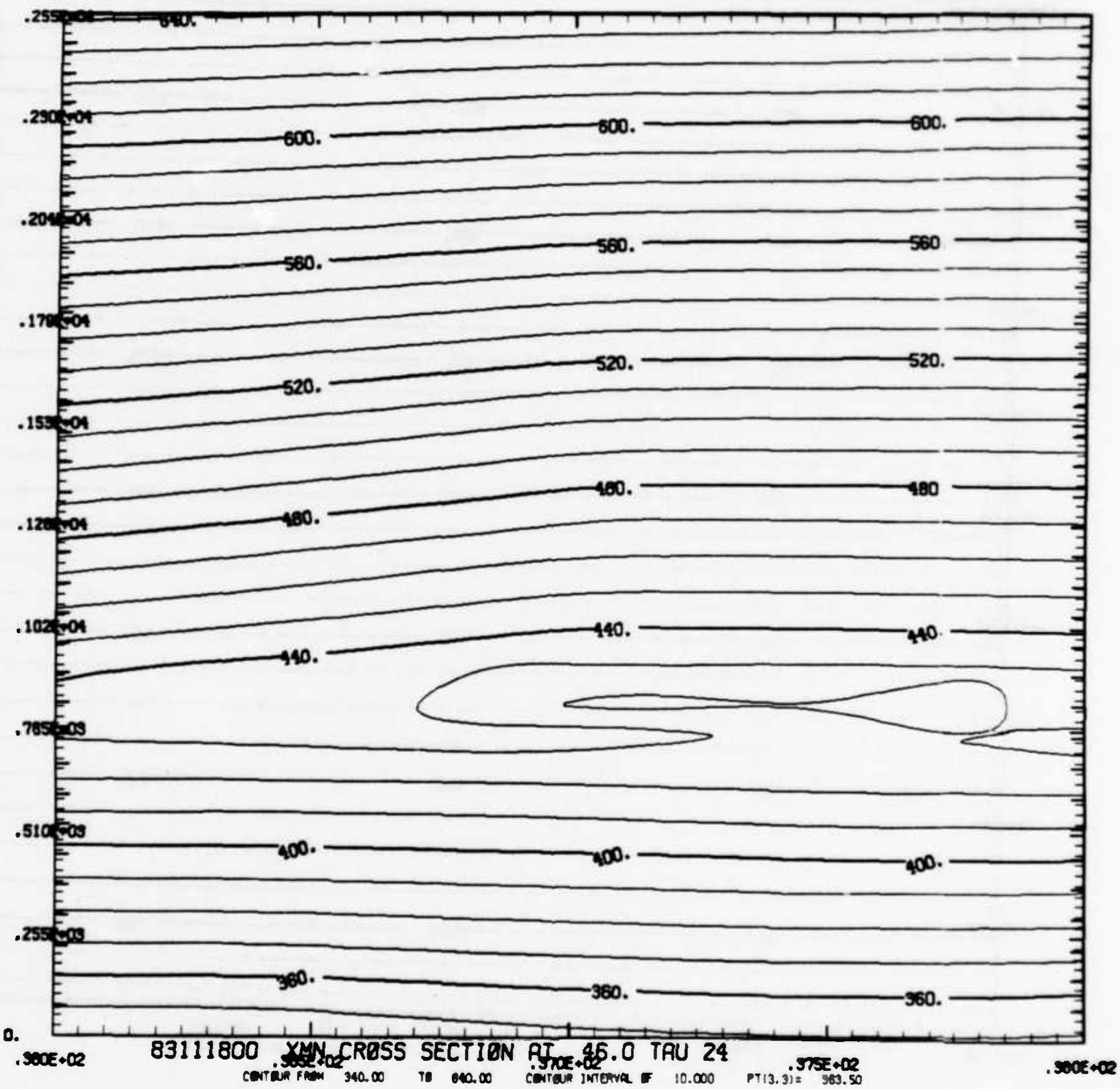

FIGURE 3-05. Vertical cross-section of NOLAPS 24 hour forecast of modified refractivity (M) (engineering notation, height in meters, longitude east, trapping layer near 800 m/2600 ft).

is discussed in subsection 4.2.5.

3.4.2 Statistical Inference. Whereas synoptic inference (see subsection 3.5.2) is mostly subjective and qualitative, statistical inference is objective and quantitative. The latter is based on empirical data and statistical analysis of discreet information. Statistical inference requires entering some table, algorithm or computer program with unambiguous known information in order to obtain a specific (though not necessarily very precise) "forecast" of unknown information. The forecasts resulting from statistical inference are never more precise than the input data. They will typically provide ranges of expected values or probabilities of occurrence.

Input for statistical methods can be from recent observation(s), from a recent analysis (a considered processed ensemble of near simultaneous recent observations), or from data output from some complex, deterministic numerical forecast model. The latter is a particular branch of statistical inference frequently referred to as Model Output Statistics (MOS).

An example of statistical inference is the work of Helvey (1979) who showed that known information from two reference levels could be used with a degree of skill to objectively infer the probability of and altitude of an elevated duct at some intervening level. In related work Sweet (1980) demonstrated good skill for certain regions in assessing the existence of ducting or normal conditions below the 850 millibar level (about 5000 feet) based on a parameter derivable from forecast model output data. But none of these or any similar techniques are routinely used operationally for ETL assessment.

Considering the large amount of output from NOGAPS which is

now being archived at FNOC, and also the potential archive of output from NORAPS, Section 5 recommends a more vigorous application of MOS techniques to the ETL assessment problem.

3.5 On-Scene Forecasting. For our purposes "near-scene" might be a better term than "on-scene" since the area of interest may well be changing from a present location to one several flying or steaming hours away. Typically, on-scene ETL forecasting tools are for a single point (or vertical column over a point), while the central site product set as discussed in subsection 3.4 is for multiple points in a two or three dimensional array.

3.5.1 On-Scene Numerical Prediction. On-scene assessment requires less resource intensive numerical models which are capable of being run in a timely manner on the smaller computers available in the near-term to the forecaster afloat. The larger and more sophisticated models for the much more powerful central site computers were discussed in subsection 3.4.1.

No numerical environmental forecast models are now operational afloat, but the introduction of HP 9845 computers to support IREPS and SNAP (Shipboard Numerical Aids Program) processing and the ongoing development of a Tactical Environmental Support System (TESS) for out-year installation on a large number of ships make models for ETL application fully feasible. One ETL-related forecast model has already been reprogrammed for the HP 9845 and a second is planned for similar conversion in the near future.

The first model, now running in a research mode on the HP 9845, is a marine atmospheric boundary layer prediction model developed by the Naval Postgraduate School (NPS) Environmental Physics Group. It is an integrated, mixed-layer model often

referred to as the "slab model". The NPS "slab model" itself is well described by Fairall et al (1981). Some results and potential applications are described in more detail by Davidson et al (1982).

The second model for which early conversion to the HP 9845 is planned, is the second-moment closure turbulence model developed at NEPRF for marine atmospheric boundary layer prediction. It is described by Burk and Thompson (1982). Central site applications for this "closure model" were described in subsection 3.4.1.3.

Both of these models are one-dimensional ("stick") models which rely on a local sounding for their initial conditions (though the "closure" model can be initialized solely with large scale model output) and both require specification of several other (but not exactly the same) local variables (for example, wind speed, sea surface temperature and subsidence) which could come from local observation and/or large scale model output.

It is safe to characterize the slab model as less complex, faster running and somewhat closer to being operationally implementable and the closure model as more sophisticated in its formulation and probably in its potential but at a substantial computational price. The slab model requires 2 to 3 minutes on an HP 9845(B)[2] for a 24 hour forecast. It is roughly projected that a current version of the closure model would require 30 to 40 minutes on an HP 9845(B)[2]. The important point though is that both are clearly affordable.

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[2]Timing is for an HP 9845(B) with the option 275 upgrade installed.

The forecaster afloat could conceivably be provided both models, or even some later third model, and use the fastest one with acceptable skill for a particular situation. For example, in the tropics where the well mixed assumption breaks down or is less important, the closure model with its much higher vertical extent (3.75 km/12,300 ft) and resolution (55 grid points) may be required to forecast the strength or mere existence of a well elevated trapping layer. The trade wind inversion at several thousand feet in altitude, which only the closure model can resolve may well have more effect on EM propagation in many areas than the lower marine inversion at only a few hundred feet which both models forecast. In other locations where the lower marine inversions dominate, the faster slab model might give acceptable results.

A similar approach which would "select the most appropriate forecast tool within operational constraints for the anticipated meteorological scenario "is suggested by Mack et al, 1983 as the basis for a marine obscuration (PBL process) forecast system. That report (Mack et al) is of further interest because it reports on an objective evaluation of five numerical models which were considered to have high potential for correctly simulating boundary layer processes and for forecasting marine stratus and fog. Among the five numerical models evaluated were both the NPS mixed-layer model and the NEPRF closure model (the latter referred to by Mack et al as "Burk's HOC (High Order Closure) model"). Significantly, their report concluded that "Burk's HOC was . . . superior to all other models and forecast approaches tested . . . (demonstrating) . . . that quantitative forecasts of boundary layer structure are possible" and recommended "that Burk's model be implemented for use in operational mesoscale forecasting when sufficient computer resources and initialization

data are available." A similar recommendation is made in Section 5 of this report.

3.5.2 Interpolation, Extrapolation and Synoptic Inference.

Interpolation is used to estimate the value of a variable at a location somewhere between actual observations. It might be used to estimate duct geometry between the force at sea and the beach, using the ship's own radiosonde and one from a coastal air station. Another not so obvious example of interpolation is that of basing a forecast on a considered interpolation between the last observation and climatology.

Extrapolation of course can also be applied to both time and space. A common first guess for T^{+1} is $T^{\circ}+(T^{\circ}-T^{-1})$. In space, if one knows that inversion height increases between eastern location A and western location B, then (without any contrary evidence) one would expect any trapping layer to be even more elevated at a more-western location C. Extrapolation within a relatively homogeneous air mass or between two similar air masses (which may be well separated in time and/or space) leads to a discussion of synoptic inference.

The synoptic situation has been defined as "the general state-of-the-atmosphere as described by the major features of synoptic charts" (Huschke, 1959). Put another way, the synoptic situation is the broad weather pattern at a particular time (past, present or future) as shown in lower-resolution cloud imagery and as depicted on common meteorological analyses or forecast charts. Using such information together with known characteristics (pre-assembled details) about the particular type of synoptic situation, it is possible to infer much about the likelihood of a trapping layer and something about its general character (for example, well elevated or near surface), but

nothing about details such as its M-gradient strength.

Synoptic inference is at best a skillful considered estimate (and at worst a bad guess!) - but a highly useful forecasting tool. Detailed techniques for applying synoptic scale information to the ETL forecast problem have recently been well documented by Helvey and Rosenthal (1983). Related information and discussion is contained in Purves (1974) and Gossard (1981).

<u>3.5.3 On-Scene Request - Central-site Response</u>. The local refractive effects forecaster is seldom cut-off from central-site or OCEANCEN support. Environmental broadcasts, alphanumeric and facsimile, provide ocean area observational data and large-scale analysis and forecast charts. By pre-sailing or enroute request, voyage-tailored products from Oceanography Command activities can also be provided.

Unfortunately, there are no products designed for ETL depiction on the regular facsimile broadcasts, nor are any such products routinely available by special request. An FNOC version of IREPS which would use a forecast refractivity profile from NOLAPS as input has not yet been thoroughly evaluated. Software to extract and package ETL information from NOGAPS and NORAPS output could be developed, but a prerequisite is some MOS development as previously discussed.

Of course in certain emergencies central-site or OCEANCEN support could become unavailable; but in other emergencies shipboard equipment or personnel could become disabled and sole reliance on shore support would be required. In general, standard procedures are for short-term, near-force forecasting to be done on-scene and for long-term, force-distant forecasting to be done centrally.

3.6 Section Summary. The instruments to observe the presence or absence and the strength of any ETLs on-scene exist, though a passive measurement system would be a valuable fleet asset. But, except for persistence, interpolation between recent observations and extrapolation of short-term trends, the Navys operational ability to forecast conditions over the horizon and into the future is severely limited. Even the ETL climatology needs improvement for both on-scene and central-site applications.

The prospects for skillful ETL forecasting at FNOC are high, however, if the predictive potential of numerical models already installed is explored as discussed in subsection 3.4.1.

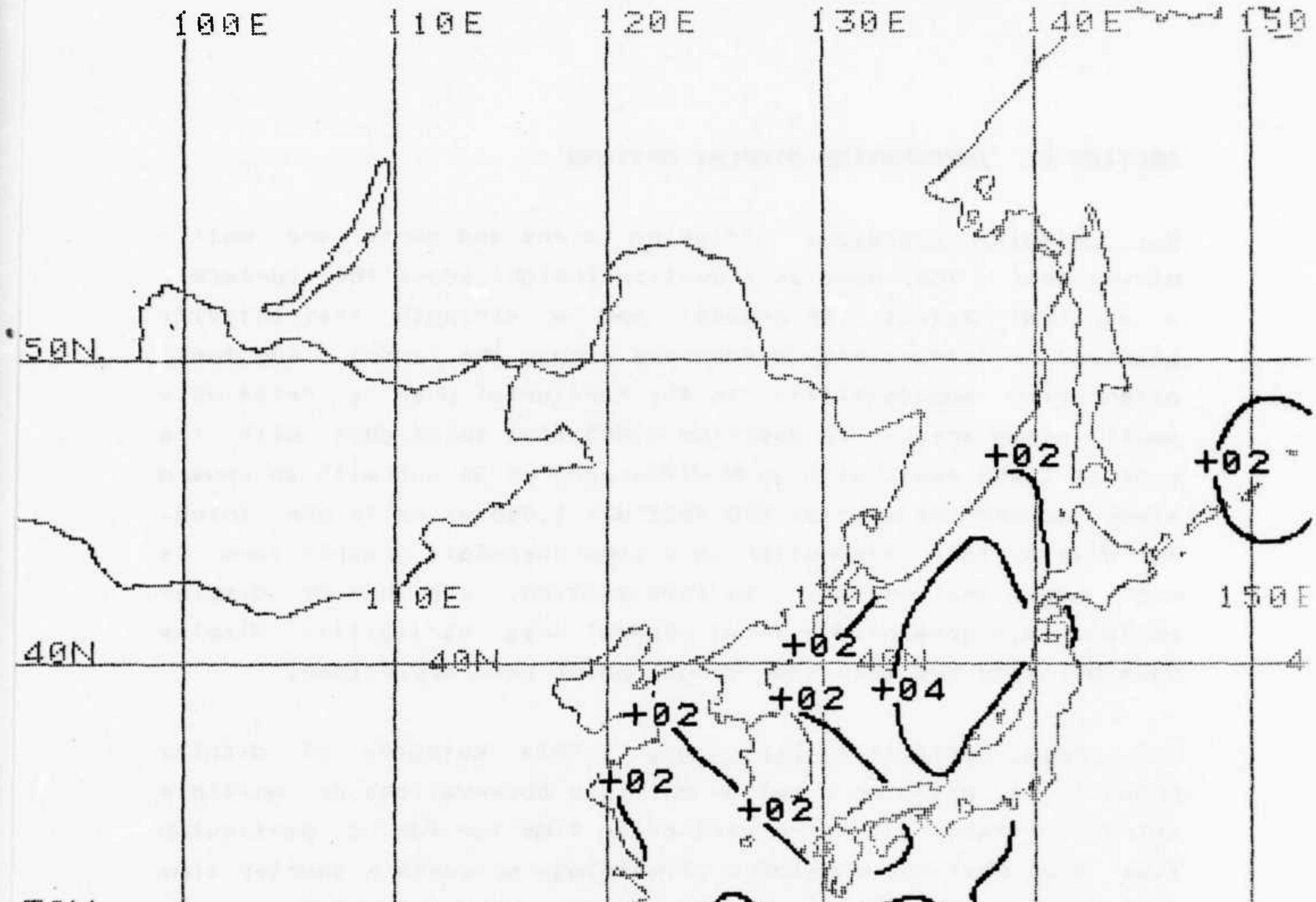
On-scene ETL forecasting ability can also be provided if a determined effort is made to convert the best of the PBL models for operational use on shipboard computers.

SECTION 4. INFORMATION DISPLAY OPTIONS

4.1 Display Overview. Trapping layers and ducts are multi-dimensional - they have an elevation (height above the surface), a vertical extent (thickness) and a strength (refractivity gradient or refractivity difference across the layer) - and these often vary substantially in the horizontal over a relatively small ocean area. To describe a 400 foot thick duct with its base at 2,000 feet, with an M difference of 30 and with an upward slope toward the west of 500 feet per 1,000 miles is one thing. To display this information in a comprehensible graphic form is much more challenging. In this section, a number of display options are presented - first several area variability display possibilities and then some single point data depictions.

4.2 Area Variability Depictions. This category of display product is based on a set of multiple observations or multiple point forecasts all for a particular time (or for a particular time span when one considers climatology or certain shorter time period-averaged data sets). Unless based on climatology, the source data would be the most recent central-site analysis or prognostic model output. Several display options in this category are discussed in subsequent subsections.

4.2.1 Duct-height Plan View. The duct-height plan view shown in Figure 4-01 is the product produced by FNOC to display evaporation duct height. If units were changed from tens to hundreds of feet, a similar contour chart could depict elevated duct (or ETL) top (or base) - but not all three (duct and layer tops coincide!). With a little imagination one can envision a second set of dashed (or contrasting color) contours for duct (or layer) thickness. It is believed however, that such a second dimension of the same parameter on a plan view is more than most



SURFACE-BASED RADAR DUCT HEIGHT (TENS OF FEET)

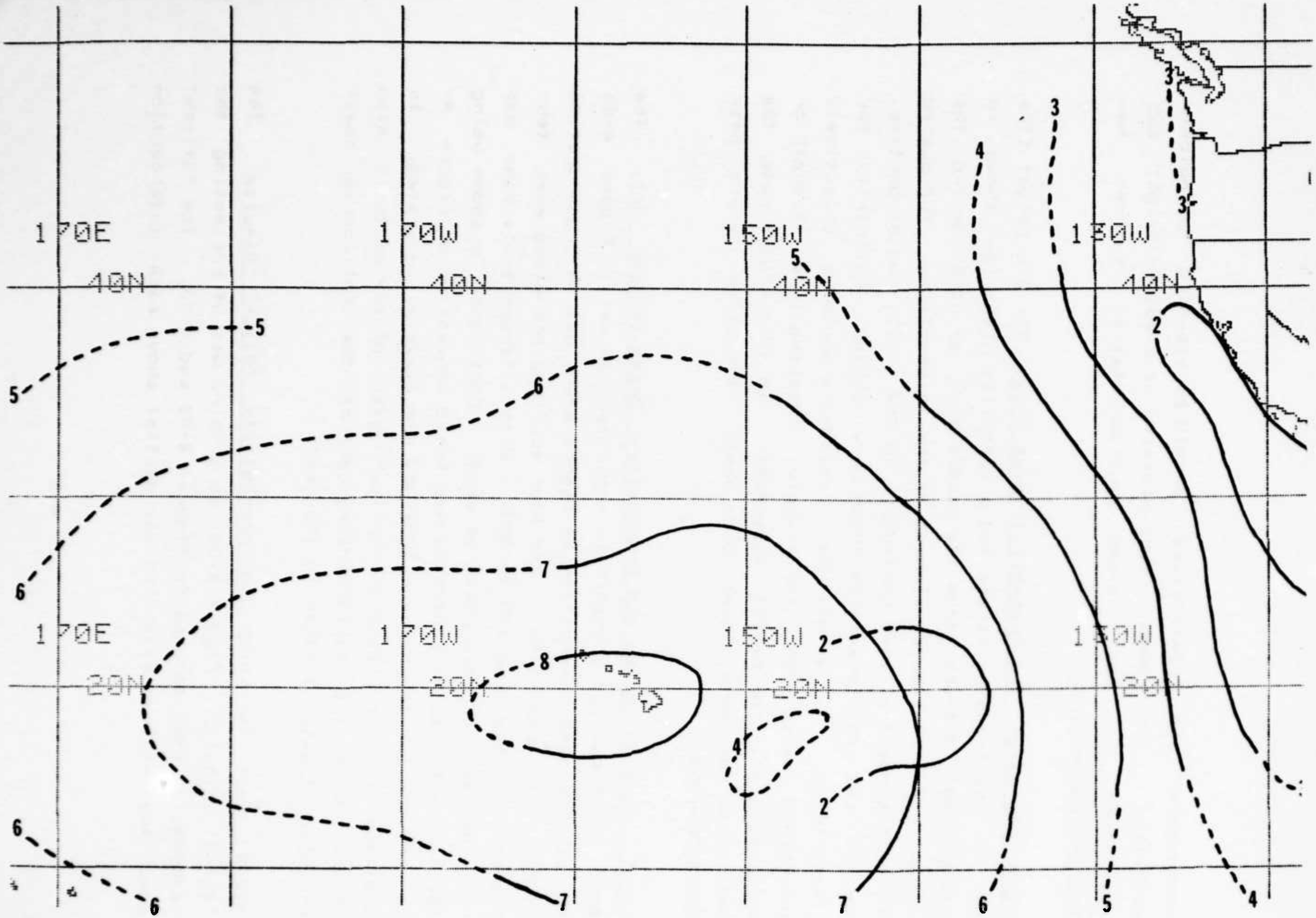
FIGURE 4-01. Duct height plan view.

"commanders" and "controllers" should be expected to quickly assimilate. (The common, over-plotting of pressure/height and temperature for the trained environmentalist involves two <u>separate</u> parameters.)

<u>4.2.2 ETL Height and Probability Plan View</u>. The ETL height (the top of the trapping layer) and probability plan view shown in Figure 4-02 differs from its predecessor by considering the probability (likelihood) element of the information. The dashed contours suggest a lower confidence in the likelihood of ducting. The 40 and 60% thresholds shown were chosen arbitrarily for illustration. In actual use, confidence would be objectively determined based upon, for example, trapping layer strength or multi-forecast (or report) agreement. In this figure note the indication of both lower and upper refractive layers near 18N/137W-150W.

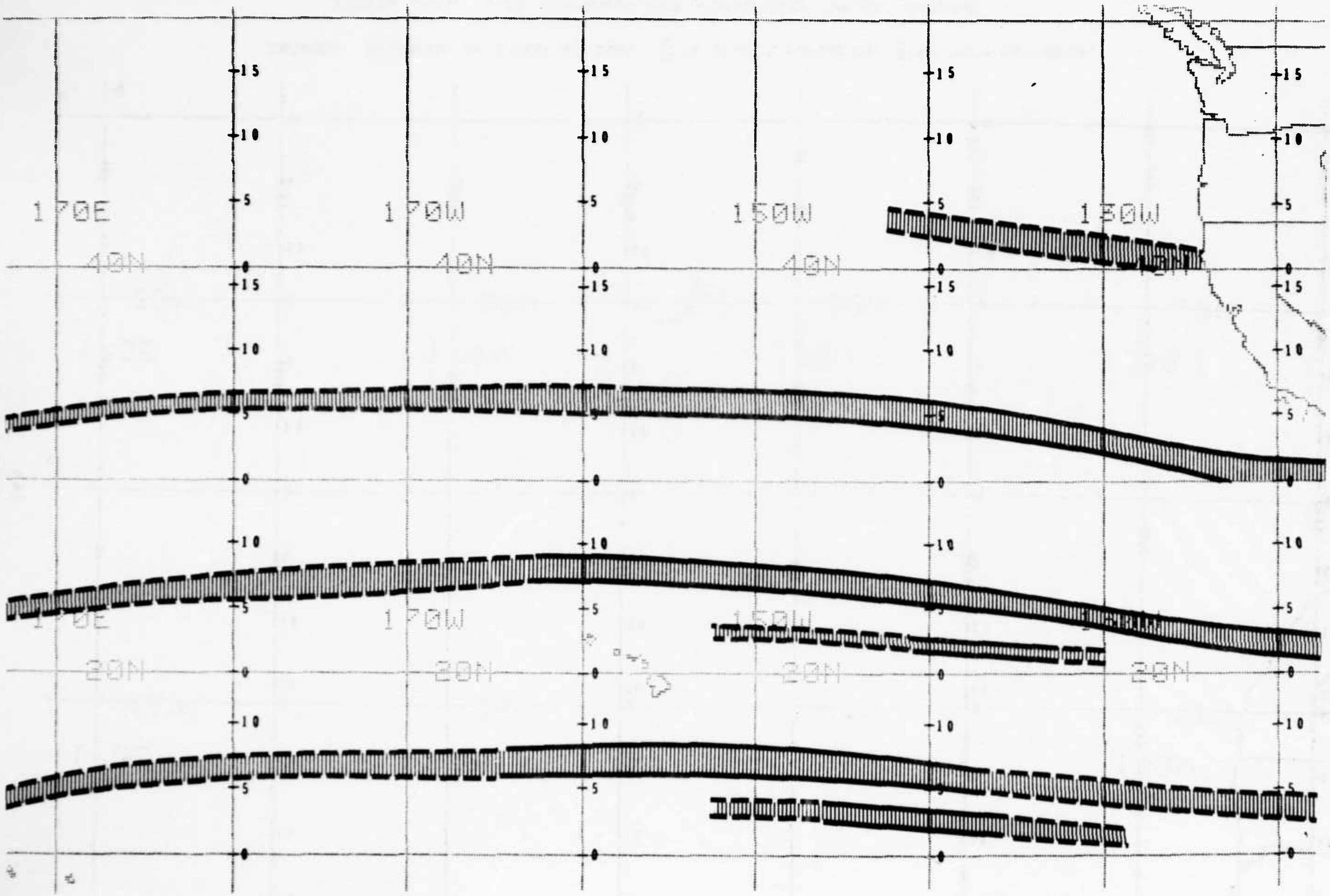
<u>4.2.3 Duct Thickness and Probability Cross-section Set</u>. The duct thickness and probability cross-section set in Figure 4-03 depicts the same information as Figure 4-02, but in cross-section rather than plan view. The four sections are along even ten-degree latitudes from 10N to 40N. With a larger scale base map five degree intervals could be used. Confidence is shown using the same arbitrarily chosen dashed solid convention of Figure 4-02 and the two layers near 18N/140W are clearly indicated. In addition the thickness or vertical extent of any ducts is also shown. Note the surface-based duct off the California coast becoming elevated further to the west.

<u>4.2.4 Duct Thickness and Probability "Stick" Display</u>. The "stick" display (Figure 4-04) is a third way of presenting the information used to prepare Figures 4-02 and 4-03. The "sticks" show the vertical extent of any duct(s) above each intersection



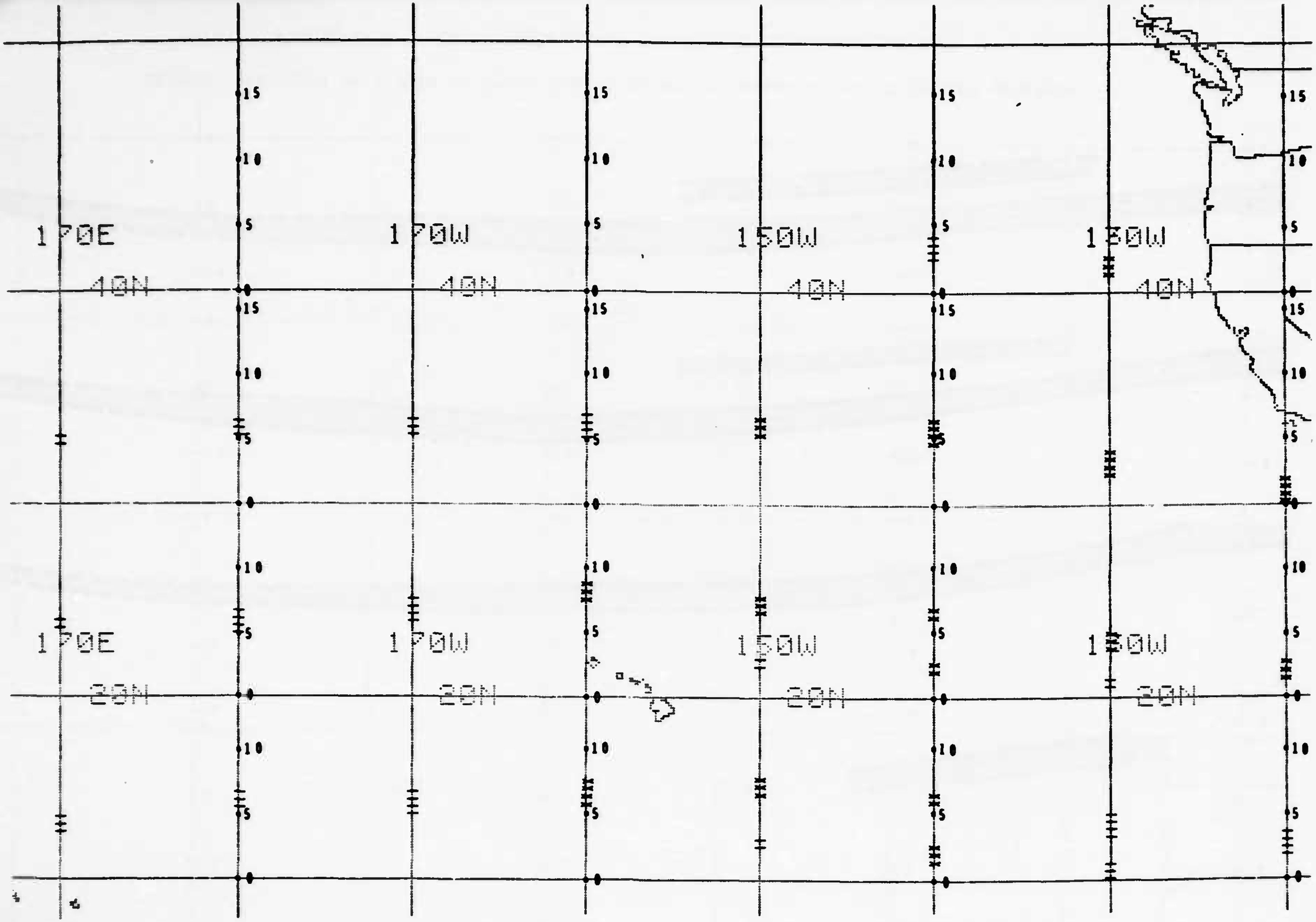
LEGEND: Contours in 1,000s of feet, dashed is 40-60% probable, solid is >60% probable.

FIGURE 4-02. ETL height and probability plan view.



LEGEND: Altitude in 1,000s of feet, dashed is 40-60% probable, solid is >60% probable.

FIGURE 4-03. Duct thickness and probability cross-section set.



LEGEND: Altitude in 1,000 of feet, ☰ is 40-60% probable, ☰ is >60% probable.

FIGURE 4-04. Duct thickness and probability "stick" display.

on the base map's latitude-longitude grid. Different duct delimiting characters are used to portray probability. A 10 degree grid is shown but a five or fewer degree spacing, particularly along latitudes, could be used if base map scale were increased. This display, like Figure 4-03, shows base, height, thickness and probability over a wide area. Its major disadvantage is the requirement to visually interpolate between "sticks". Its advantage is that, because it contains only characters or symbols rather than vectors to be plotted, it could be more quickly transmitted to a remote site for display on a standard base map.

<u>4.2.5 NOLAPS M-Profile and Duct Display</u>. The only depiction of ETL horizontal variability described in this subsection which is actually available at FNOC is the NOLAPS M-profile and Duct Display (Figure 4-05). The NOLAPS (Navy Operational Local Atmospheric Prediction System) was described in subsection 3.4.1.3. This particular example depicts the results from a three by five array of concurrent NOLAPS 24 hour point forecasts over the Eastern Mediterranean. The array is shown in Figure 4-06. Note that the NOLAPS display provides both the computed refractivity for each point in M-profile plot form as well as a depiction of any ducts in bar display form to the right. Evaporation duct strength is indicated by a vertical arrow at the bottom, which points to the air-sea interface M value, and its thickness in meters is printed near the lower right corner of each plot (e.g. ED=7.4). Should a duct occur between 2.0 and 3.75 km (the top of the current models vertical grid), there is provision within the NOLAPS display software to automatically adjust the ordinate scaling so as to include the duct in the display. Some prospective operational users of this display may prefer only the M-profile or only the duct bar portion. Such an option could be easily accommodated.

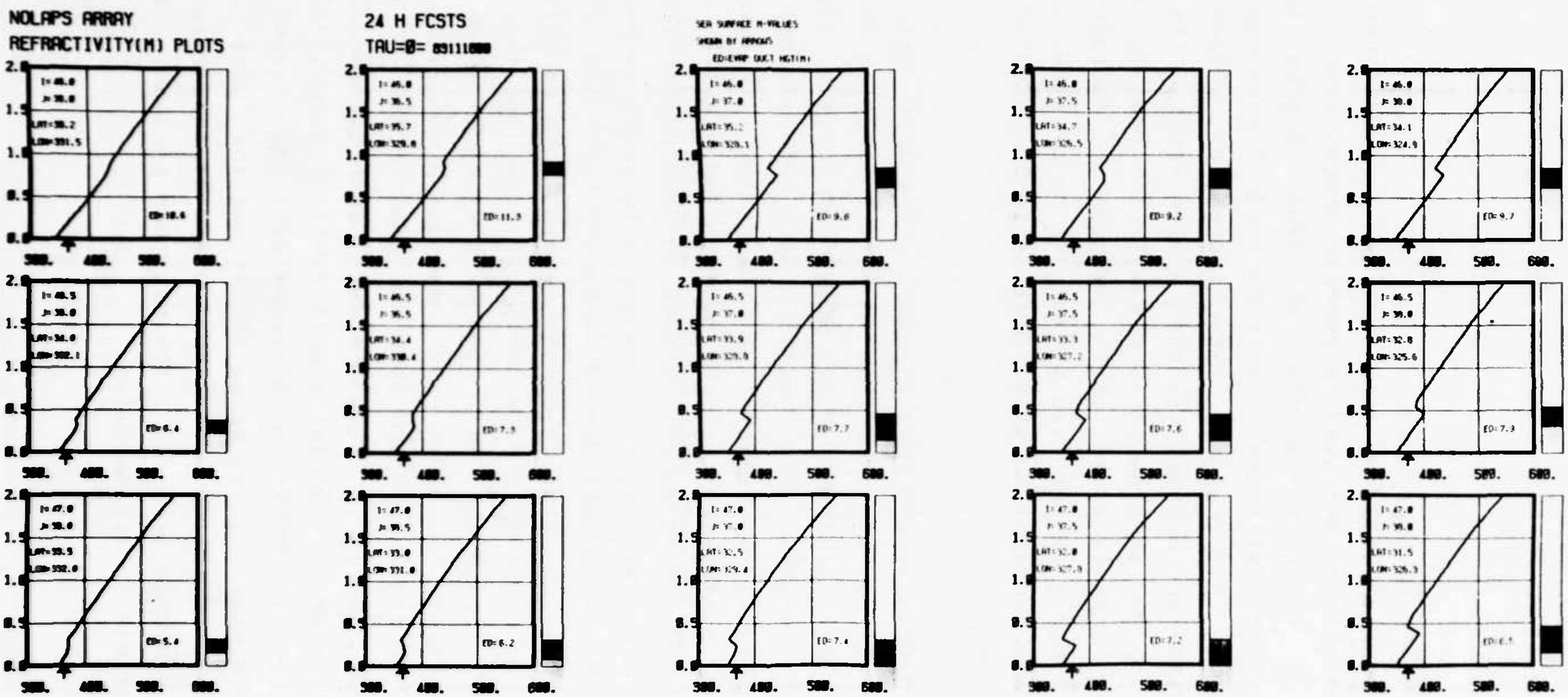


FIGURE 4-05. NOLAPS M-profile and duct display (height in Km).

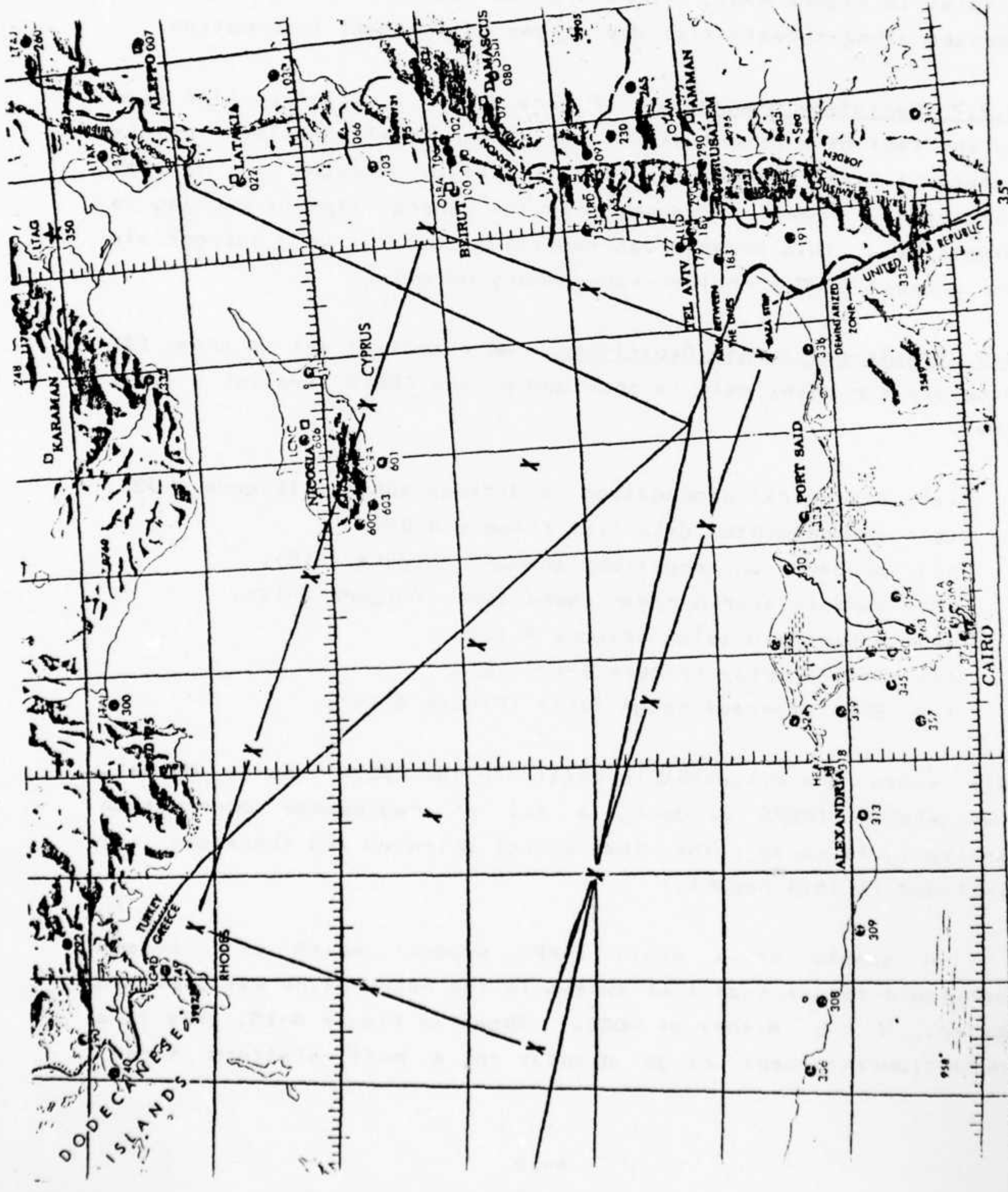


FIGURE 4-06. The NOLAPS Eastern Mediterranean Array.

4.2.6 Along-track Duct Displays. A variation on the latitudinal cross-section (Figure 4-03) is presented as an along-track display in Figure 4-07. Here are two possible along-track (or perhaps along-threat-axis) depictions of the same information.

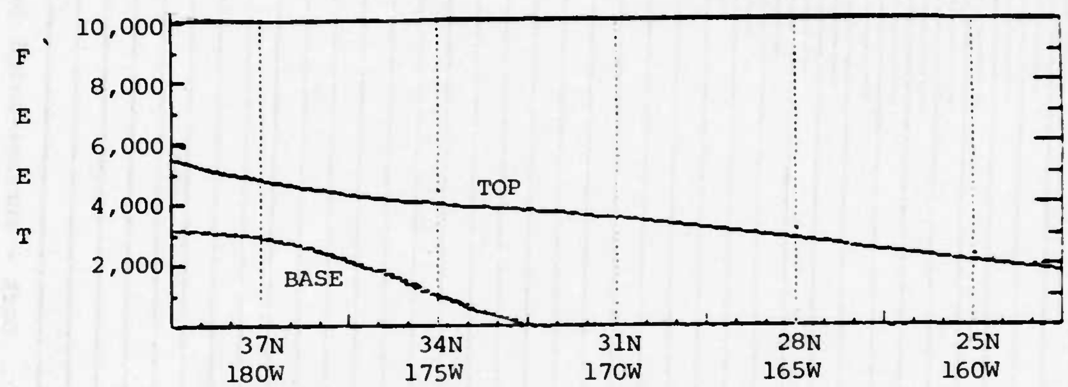
4.2.7 Duct-type Plan View. Figure 4-08, a duct-type plan view is the last of a potentially large number of alternatives in this category; the reader has likely already thought of several variations. Here, however, only the general type of ducting is displayed. This broad brush depiction could be very appropriate for a Fleet CINC's whole-ocean-summary briefing.

4.3 Single-point Data Depictions. An excellent set of seven ETL displays for point data is provided by the IREPS System. These are:

(a) historical propagation conditions summary (Figure 3-03),
(b) environmental data list (Figure 4-09),
(c) propagation conditions summary (Figure 4-10),
(d) surface search radar range table (Figure 4-11),
(e) coverage display (Figure 4-12),
(f) loss display (Figure 4-13), and
(g) ESM intercept range table (Figure 4-14).

All seven are discussed in detail in the IREPS User's Manual. (An eighth IREPS product, a set of radiosonde observation analyses, is cause rather than effect oriented and therefore not included in this report.)

A sample of a ninth IREPS product which will become available to users of that system in the near future was provided by Mr. H. V. Hitney of NOSC. Shown in Figure 4-15, this is a detection/intercept range display for a multi-platform force.



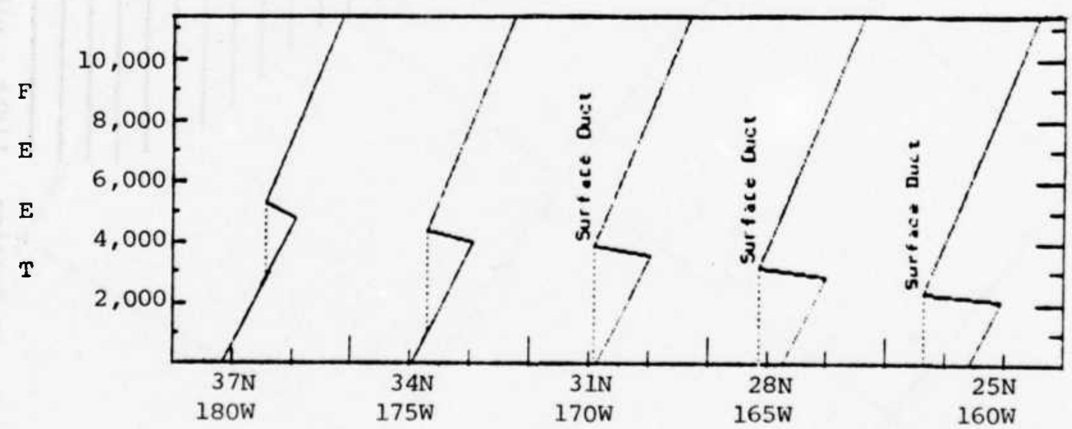
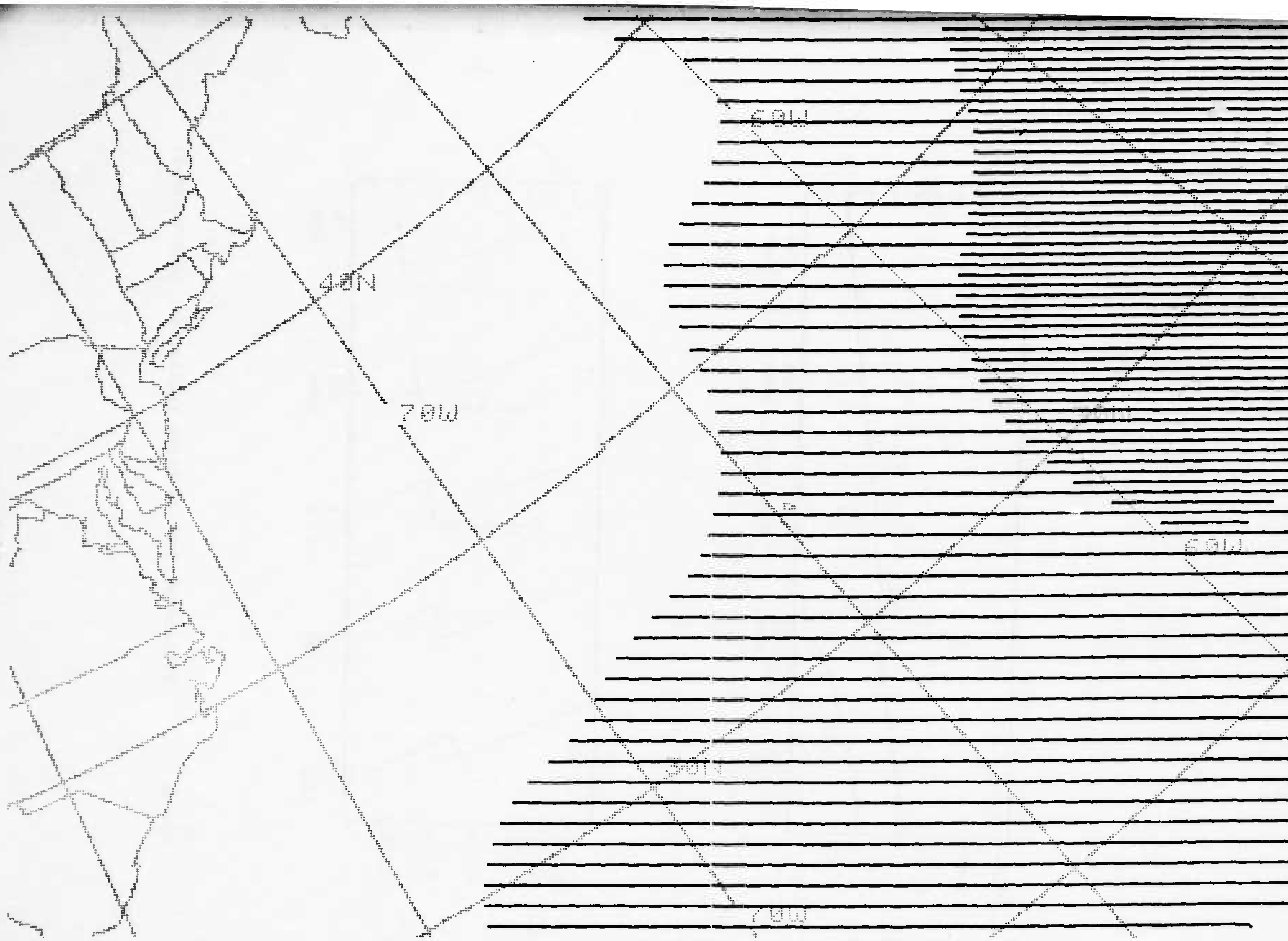


FIGURE 4-07. Along-track duct displays (equivalent information).



LEGEND: Clear - no ducting, Light - elevated ducting, Dark - surface-based ducting.

FIGURE 4-08. Duct-type plan view.

IREPS REV 2.0

**** ENVIRONMENTAL DATA LIST ****

LOCATION: 31 56N 118 36W
DATE/TIME: 17 JUN 0045Z

WIND SPEED 12.0 KNOTS

EVAPORATION DUCT PARAMETERS:
SEA TEMPERATURE 18.2 DEGREES C
AIR TEMPERATURE 15.1 DEGREES C
RELATIVE HUMIDITY 89 PERCENT
EVAPORATION DUCT HEIGHT 28.0 FEET

SURFACE PRESSURE = 1008.0 mB
RADIOSONDE LAUNCH HEIGHT = 60.0 FEET

LEVEL	PRESS (mB)	TEMP (C)	RH (%)	DEW PT DEP(C)	FEET	N UNITS	N/Kft	M UNITS	CONDITION
1	1,008.0	15.1	89.0	1.8	60.0	340.0	-28.2	342.9	SUPER
2	1,000.0	14.2	87.0	2.1	281.6	333.8	15.6	347.2	SUB
3	993.0	13.9	95.0	0.8	476.6	336.8	-10.9	359.6	NORMAL
4	982.0	13.3	97.0	0.5	785.3	333.4	-176.4	371.0	TRAP
5	972.0	20.4	25.0	20.8	1,071.8	282.9	27.2	334.2	SUB
6	962.0	21.5	34.0	16.6	1,364.9	290.9	-28.9	356.2	SUPER
7	949.0	21.5	27.0	19.9	1,751.3	279.7	-9.4	363.5	NORMAL
8	862.0	20.6	25.0	20.8	4,477.3	254.0	-9.5	468.2	NORMAL
9	850.0	19.7	25.0	20.7	4,873.5	250.2	-7.6	483.4	NORMAL
10	807.0	20.0	25.0	20.7	6,339.1	239.0	-6.0	542.3	NORMAL
11	726.0	14.5	34.0	15.8	9,299.4	221.2	-8.9	666.1	NORMAL
12	700.0	11.8	34.0	15.5	10,305.6	212.2	------	705.3	------

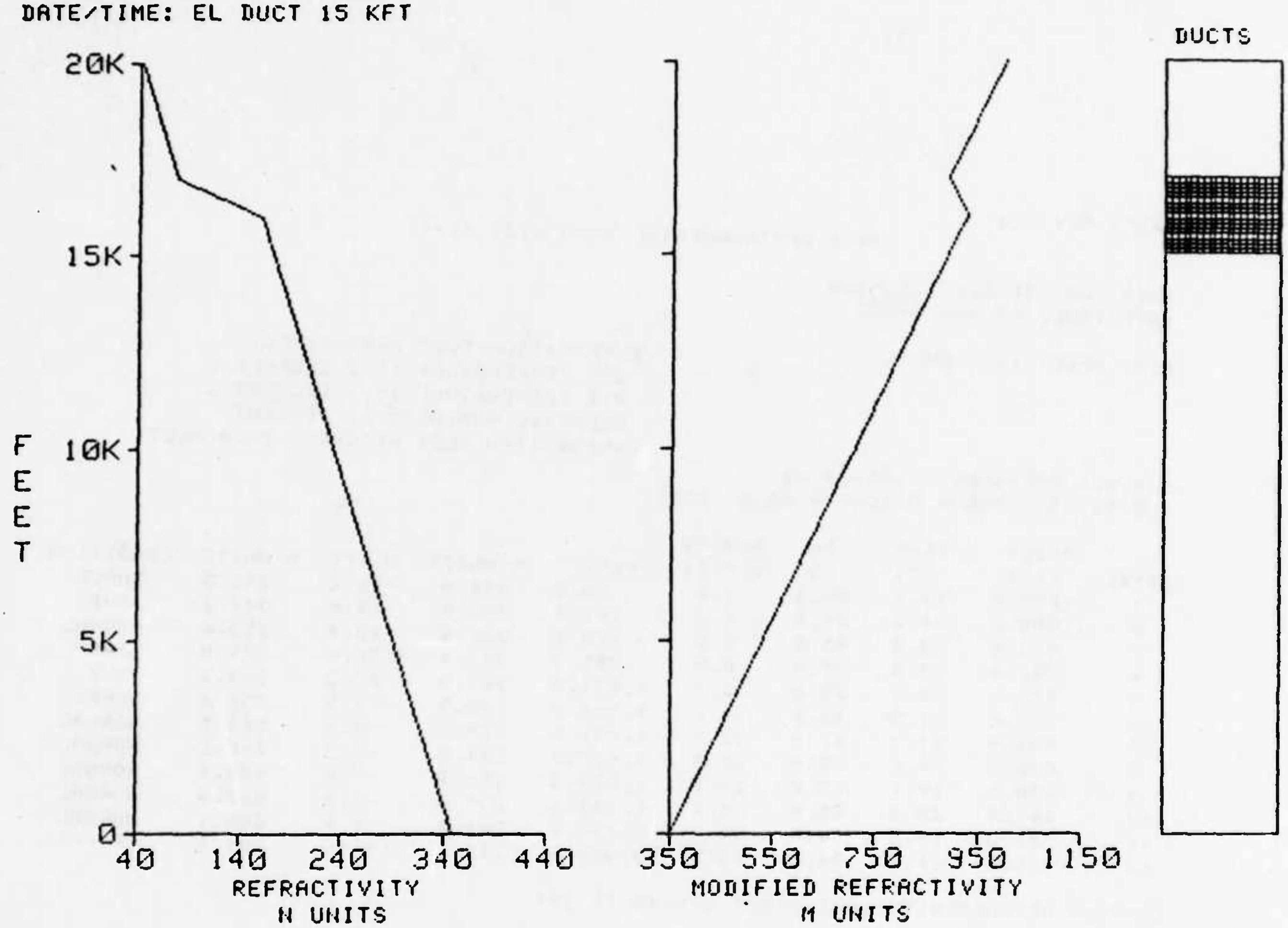
SURFACE REFRACTIVITY: 341 --SET SPS-48 TO 344

FIGURE 4-09. Environmental data list product (Hitney et al, 1981).

IREPS REV 2.0

**** PROPAGATION CONDITIONS SUMMARY ****

LOCATION: NOT SPECIFIED
DATE/TIME: EL DUCT 15 KFT



WIND SPEED= 0.0 KNOTS

EVAPORATION DUCT HEIGHT= 0.0 METRES
= 0.0 FEET

SURFACE-TO-SURFACE
NORMAL RANGES AT ALL FREQUENCIES

SURFACE-TO-AIR
NORMAL RANGES AT ALL ALTITUDES.

AIR-TO-AIR
EXTENDED RANGES FOR ALTITUDES BETWEEN15,000 AND17,000 FEET
POSSIBLE HOLES FOR ALTITUDES ABOVE 17,000 FEET

SURFACE REFRACTIVITY: 350 --SET SPS-48 TO 344

FIGURE 4-10. Propagation conditions summary product (for an elevated duct) (Hitney et al, 1981).

IREPS REV 2.0

***** SURFACE SEARCH RADAR RANGE TABLE *****

LOCATION:
TIME:

SURFACE SEARCH RADAR:

RADAR ANTENNA HEIGHT: FEET

U S SHIP TYPE/CLASS	DETECTION RANGE IN NM MIN	AVG	MAX
CV/CVN CG/CGN DD/DDG			
FF/FFG LCC LHA			
LPH LKA LPD			
LSD LST AE/AF AO/AOE/AOR			

SOVIET SHIP TYPE/CLASS	DETECTION RANGE IN NM MIN	AVG	MAX
KIEV CLASS MOSKVA CLASS CLG			
CG/CC/CA DD/DDG FRIGATE			
CORVETTE OSA/STENKA CLASS PRIMORYE CLASS AGI			
LENTRA CLASS AGI OKEAN CLASS AGI			

EVAPORATION DUCT HEIGHT= METRES.
= FEET

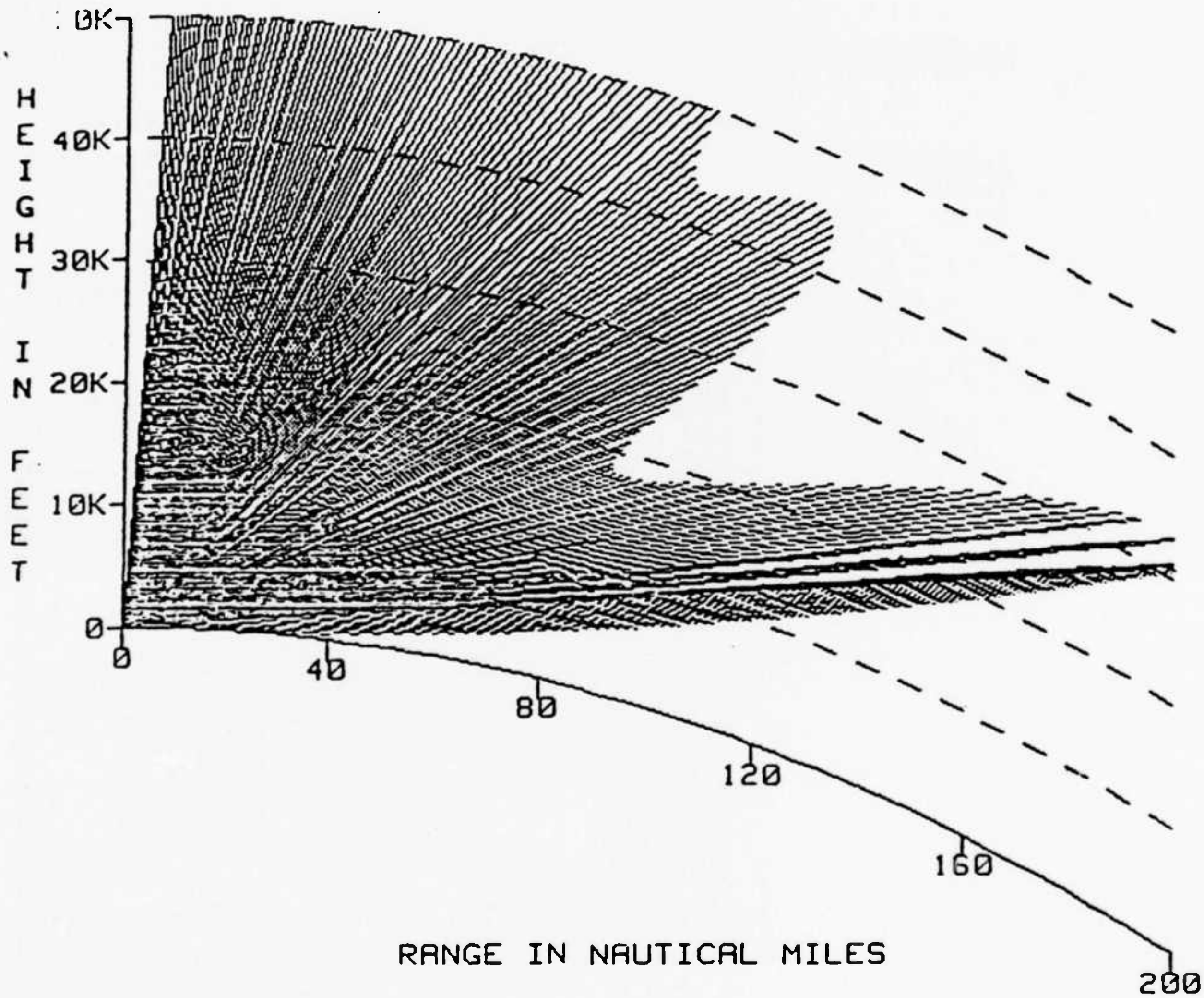
FIGURE 4-11. Surface search radar range table format (Hitney et al, 1981).

IREPS REV 2.0

*** COVERAGE DISPLAY ***

SPS-48

LOCATION: NOT SPECIFIED
DATE/TIME: STANDARD



BASED ON DETECTION OF ARBITRARY SIZE AIR TARGET
AT A FREE SPACE RANGE OF 120 NAUTICAL MILES

SHADED AREA INDICATES AREA OF DETECTION OR COMMUNICATION

FREE SPACE RANGE: 120.0 NAUTICAL MILES
FREQUENCY: 3000 MHZ
TRANSMITTER OR RADAR ANTENNA HEIGHT: 100.0 FEET

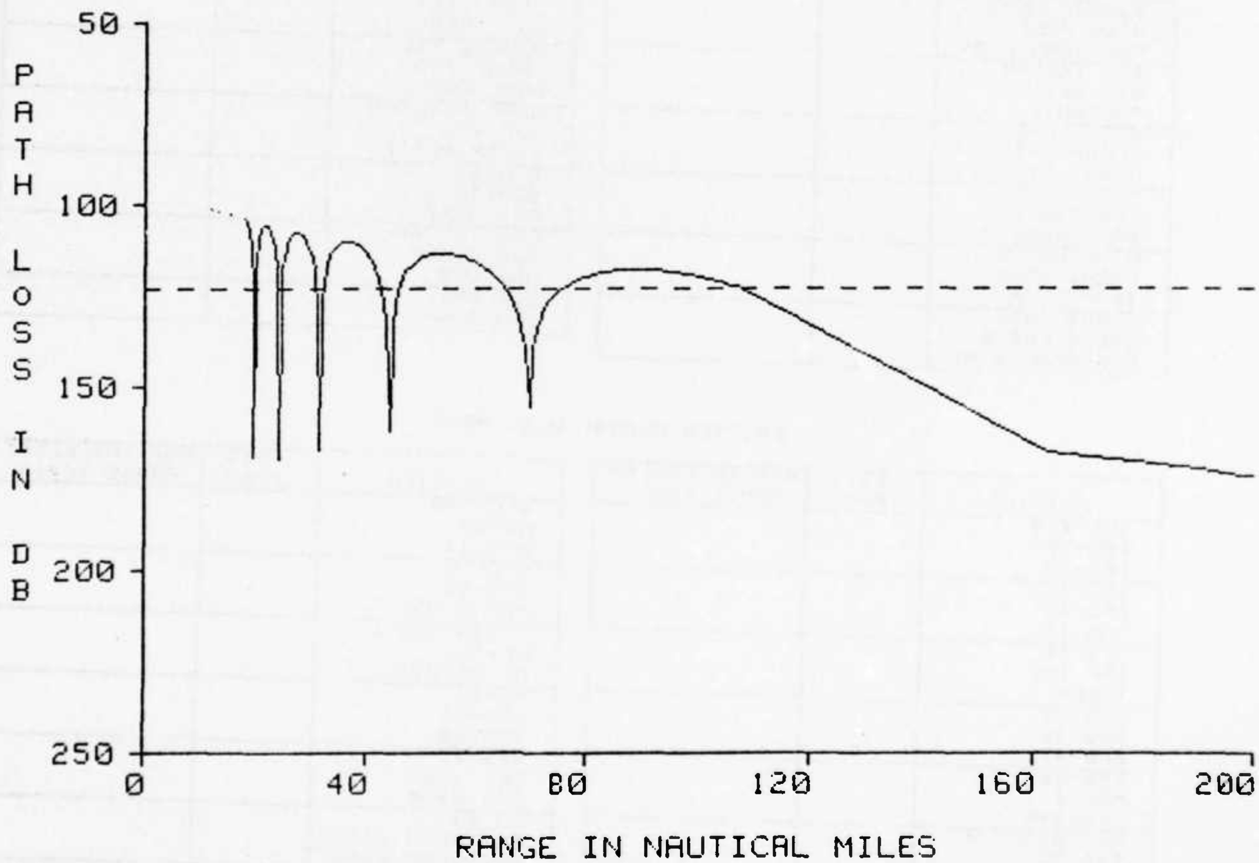
FIGURE 4-12. Coverage display product (for an SPS-48 radar; standard atmosphere) (Hitney et al, 1981).

IREPS REV 2.0

**** LOSS DISPLAY ****

SPS-37/43

LOCATION: NOT SPECIFIED
DATE/TIME: STANDARD



BASED ON DETECTION OF ARBITRARY SIZE AIR TARGET
AT A FREE SPACE RANGE OF 85 NAUTICAL MILES

DASHED LINE INDICATES DETECTION, COMMUNICATION, OR INTERCEPT THRESHOLD

FREE SPACE RANGE: 85.0 NAUTICAL MILES
FREQUENCY: 220 MHZ
TRANSMITTER/RADAR HEIGHT: 140.0 FEET
RECEIVER/TARGET HEIGHT: 10000.0 FEET

FIGURE 4-13. Loss display product (for an SPS-37/47 radar; standard atmosphere) (Hitney et al, 1981).

IREPS REV 2.0

***** ESM INTERCEPT RANGE TABLE *****

LOCATION:
TIME:

ESM RECEIVER: WLR-1 CV

EMITTER CLASS: SOVIET

EMITTER	FREQ (MHz)	MAX INTERCEPT RANGE (nmi)
KNIFE REST A KNIFE REST B CROSS BIRD		
SQUARE HEAD HIGH POLE FAN SONG E MG		
TOP TROUGH BIG NET TOP SAIL		
HIGH LUNE SCOOP PAIR HEAD NET		
SLIMNET LOW SIEVE BALL END		
HIGH SIEVE FRONT DOOR TRAP DOOR		
STRUT PAIR STRUT CURVE FAN SONG E MT		

EMITTER	FREQ (MHz)	MAX INTERCEPT RANGE (nmi)
HEADLIGHT MUFF COB POP GROUP		
BASS TILT DRUM TILT OWL SCREECH		
SQUARE TIE SNOOP TRAY PEEL GROUP		
HAWK SCREECH TOP BOW SNOOP PLATE		
DONETS DONETS-2 POT HEAD		
LOW TROUGH SUN VISOR NEPTUNE		
DON KAY DON/DON-2		

EMITTER CLASS: U.S. NAVY

EMITTER	FREQ (MHz)	MAX INTERCEPT RANGE (nmi)
SPS-43A SPS-29 SPS-37		
SPS-37A SPS-32 SPS-40		
SPS-49 IFF INT TACAN		
SPS-39 SPS-42 SPS-48		
SPS-52 MK-26 SPS-39A		
MK-35/MOD 0 SPS-33 SPS-30		
SPN-43 SPN-6 SPS-10		
SPG-49 ACQ SPG-51 MK-37		
BPS-5,9,11-15 MK-13 MK-34		

EMITTER	FREQ (MHz)	MAX INTERCEPT RANGE (nmi)
SPG-53A MK-68 SPG-34		
SPG-50 SPQ-9A MK-25/MOD 3		
MK-35/MOD 2 MK-56 MK-25/MOD 2		
MK-87 SPN-35 SPS-46		
SPS-53 CPR 1500 CPR 2900		
LN 66 RAYTHEON 2502 RAYTHEON 2840		
RAYTHEON 1900 DECCA 202 DECCA 914		
HEL-A 18/9 SPS-55 SPN-12		
MK-115 SPG-53B SPN-41		

EVAPORATION DUCT HEIGHT= METRES
= FEET

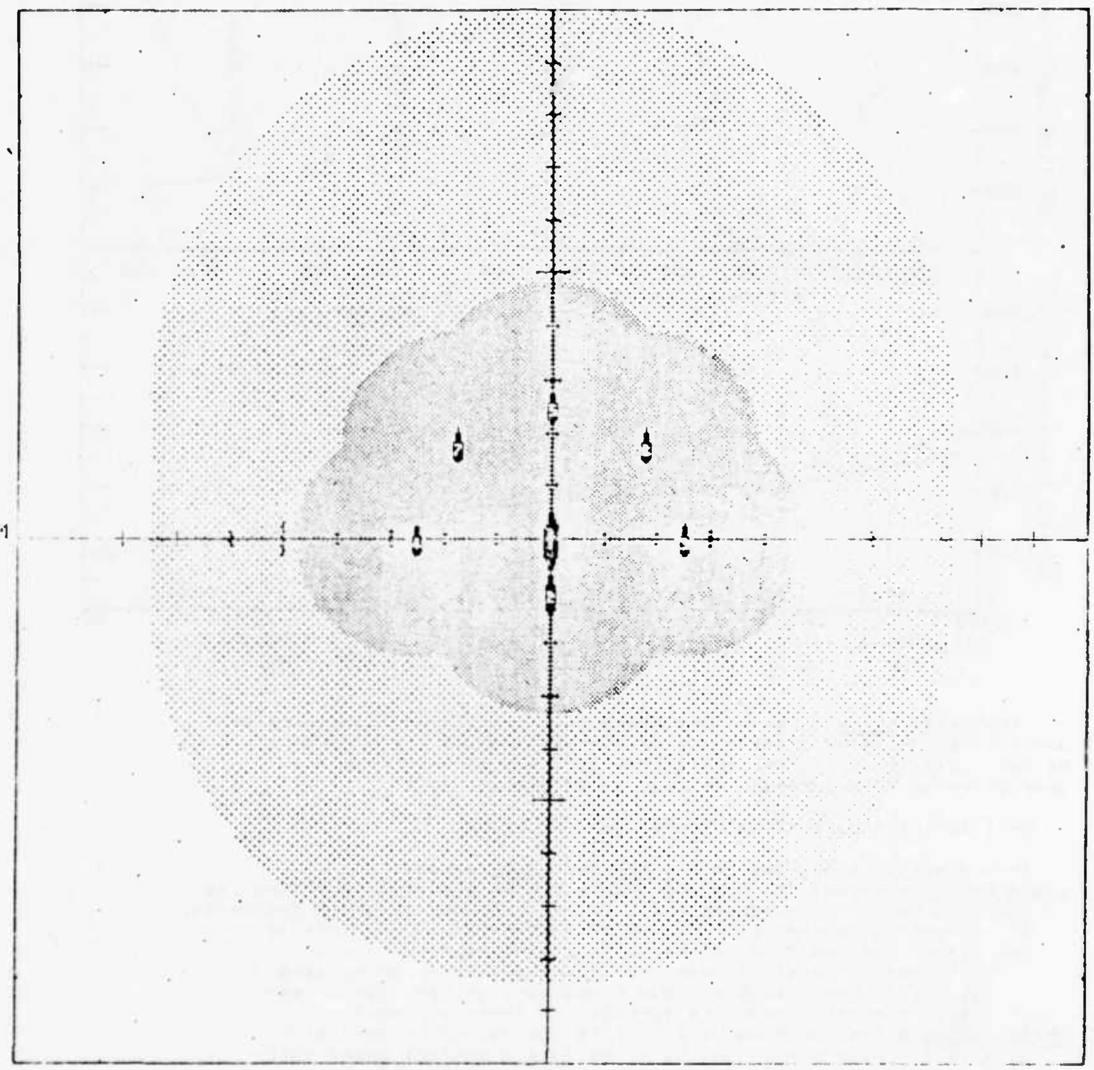
FIGURE 4-14. ESM intercept range table format (Hitney et al, 1981).

************************ CLASSIFICATION ************************

**** MIXED PLATFORM DETECTION/VULNERABILITY ****

LOCATION:
DATE/TIME:

EVAPORATION DUCT HEIGHT= 0 METRES

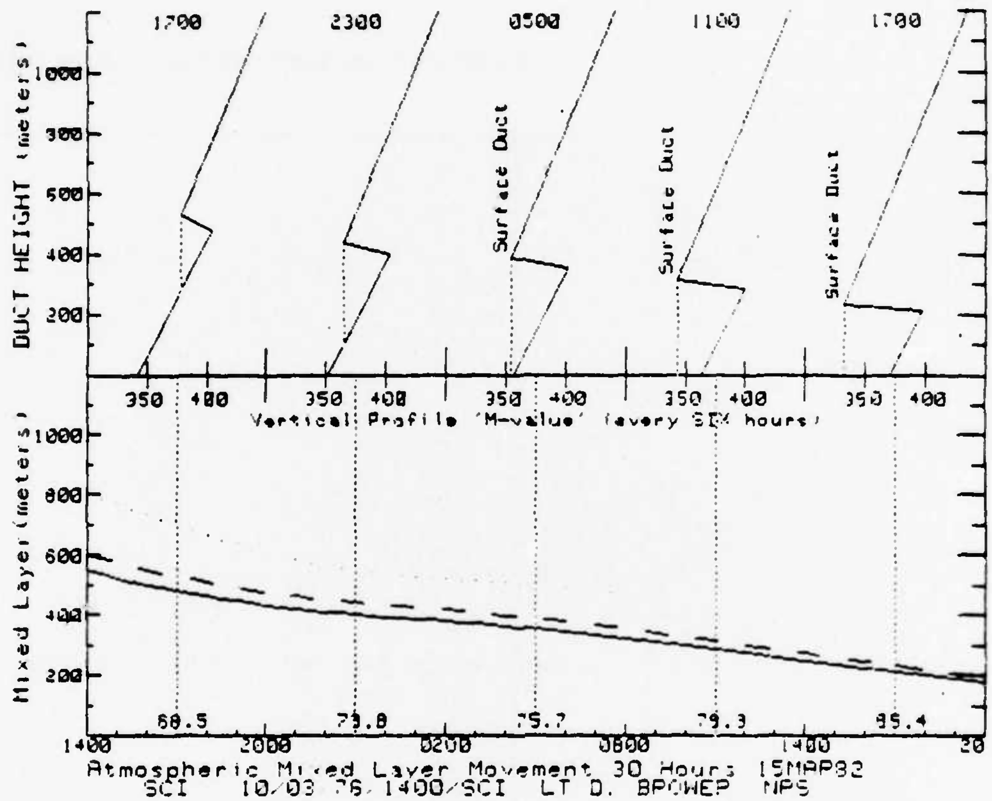


DETECTION INTERCEPT

	SHIP	BEARING	RANGE
1	USS CONSTELLATION (CV-64)	000	0
2	USS SACRAMENTO (AO-38)	180	10
3	USS HEWITT (DD-963)	090	25
4	USS ALPHA (DD-972)	270	25
5	USS BRAVO (CG-24)	000	25
6	USS CHARLIE (FF-1071)	045	25
7	USS DELTA (FF-1071)	315	25

****************************** CLASSIFICATION ******************************

FIGURE 4-15. Multi-platform coverage display product.



The <u>possibility</u> of a surface based duct (SBD) is indicated and only due to the 'M' value greater at the surface than at the inversion height. Variation in the vertical structure must be emphasized when briefing this forecast in that a SBD may not exist.

This is a SIMPLIFICATION of the real structure.

This display is divided into <u>UPPER</u> and <u>LOWER</u> windows:

<u>LOWER</u> <u>WINDOW</u> displays the top and middle of the elevated layer and its forecast continued movement for a thirty hour period after beginning. At the bottom is the Relative Humidity at each six hour period. The lightly dotted line is the lifting condensation level.
'[With enough moisture near the inversion, this can be used as a flag for possible cloud formation, or for high mixed-layer humidity, near the surface, to forecast fog.]

<u>UPPER</u> <u>WINDOW</u> picks out M-value structure (using only 4 points) at each six hour period and will indicate a surface based duct only if the elevated M-value is less than or within 5 of the surface M-value. The sampled times are displayed at top.

FIGURE 4-16. Single-point time-series product (Brower, 1982).

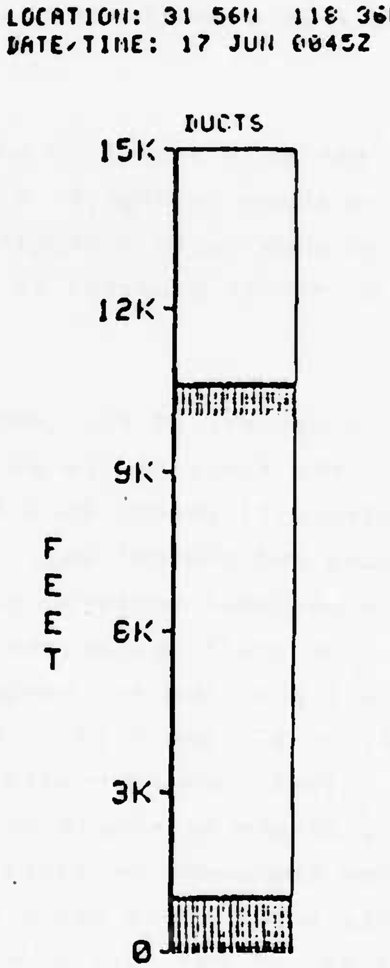


FIGURE 4-17. Bar display (showing a surface based duct and an elevated duct at the same location).

Note that this interesting and informative horizontal display is based on a single point observation and is not a function of environmental variability in space.

An interesting single-point time series display as shown in Figure 4-16 was extracted from a Naval Postgraduate School Thesis (Brower, 1982).

A much simplified, bar only variation on the IREPS summary product (Figure 4-10) is shown in Figure 4-17. This display could be modified to also show layer strength by simply plotting M-unit layer difference or M-unit gradient to the immediate right of bar shading.

<u>4.4 Section Summary</u>. A variety of ETL graphic display options have been presented. But the final choice of a product(s) from a menu like that illustrated will depend to a large extent on the level of tactical command and control and, perhaps nearly as much, on the commander's personal preference. For example: an AEW squadron commander or staff operations officer would be interested in the detail provided by range tables and loss displays (Figures 4-11, 4-12 and 4-13); but a battle group commander or numbered fleet commander afloat might be fully satisfied by the multi-platform or simple bar displays (Figures 4-15 and 4-17). A force commander or fleet commander in chief ashore interested in large ocean areas would obviously prefer an area depiction but whether or not this should be detailed like the NOLAPS display (Figure 4-05) or should be very simple like the duct-type plan view (Figure 4-08) is probably best determined by giving the commander concerned his choice.

SECTION 5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary Conclusions.

5.1.1 Central-site-related Conclusions. The Navy's ability to provide displays of ducting conditions over large ocean areas in support of C^2 ashore is severely lacking. There are three principal reasons for this situation:

First, refractivity (or the determining lower atmospheric structure) is not regularly observed with nearly close enough horizontal spacing to provide a coherent large-area depiction of "present" (recent past) conditions.

Second, with one exception (NOLAPS), the numerical prediction models at the central site (FNOC) which might be capable of providing information on "near-future" refractive conditions (out to about two days in advance) have not been investigated with respect to ETL assessment applications.

Third, there is no central-site software immediately available with which to prepare and transmit depictions of the horizontal variability of refractive conditions - not even the seasonal average conditions which could be helpful if only a digitized ETL climatology were accessible from FNOC's larger computers.

Fortunately, the improved prediction models required for central-site ETL forecasting are in advanced development at NEPRF, improved statistical forecasting techniques for use with model output are feasible and the technology and computer power required for C^2-user-oriented display development, production and dissemination are potentially available at FNOC.

5.1.2 On-scene-related Conclusions. The Navy's ability to assess the existence of ETL's on-scene is satisfactory. With the fleet introduction of refractometers it will improve substantially. However, the lack of a passive shipboard ETL sensor system is unfortunate.

The Navy's ability to assess the likelihood of ETL's in unobserved near-scene areas or at some future time is unsatisfactory, but has the potential of improving greatly. Significant improvement could be realized by reanalyzing the standard ETL climatology, by implementing an ETL forecasting capability in IREPS/TESS, and by improving fleet access to central-site forecast model output.

The Navy's ability to display ETL-related information for C^2 on-scene is highly satisfactory because of IREPS and it will improve as more ships are IREPS equipped or programmed for TESS. When IREPS/TESS is provided with an ETL forecast capability its product set should be expanded to include a variabilty-with-time display.

5.2 Recommended Actions.

5.2.1 Central-site-related Recommendations.

5.2.1.1 Digitize the Elevated Duct World Contour Maps. The thirteen world contour maps and four month-of-occurrence plots of elevated duct information contained in Miller et al (1979) comprise a summary ETL climatology which should be made more accessible for C^2 applications. This information, isopleths and plots, should be expeditiously digitized and placed in a display graphic format suitable for NEDS display and for transmittal to

non-NEDS equipped C^2 activities ashore. When and if the IREPS ETL climatology is reanalyzed as recommended in subsection 5.2.2.2 below, that reanalysis should be considered a likely candidate to replace or supplement the world contour maps addressed above.

5.2.1.2 Explore MOS from NOGAPS PBL. The NOGAPS model, even with its vertically constrained PBL, represents the only potential source of objective ETL forecasts on a worldwide basis. Several of its discretely forecast variables or derivables are ETL related (for example, the potential temperature and specific humidity jumps across the top of the PBL). These data are already being (or should be) archived. A pilot study using MOS (Model Output Statistics) techniques should be undertaken to establish the degree of skill the NOGAPS output has for assessing ETL presence, geometry and/or strength. Such an archiving and pilot effort is particularly appropriate with the recent and probably long-term operational shift from the six to the nine layer version of NOGAPS.

5.2.1.3 Explore MOS from NORAPS PBL. Since NORAPS now includes a highly sophisticated and truly floating PBL, it is strongly recommended that a commitment be made for an early evaluation of NORAPS PBL output and MOS techniques as a way to provide skillful forecasts of ETL's over wide geographic areas of immediate and high operational interest.

5.2.1.4 Establish Area Variability Display Preferences. The display options presented in subsection 4.2 should be forwarded to the Regional Oceanography Centers for their comment, suggested alternatives and key-customer's preferences. These opinions and suggestions should provide the basis and justification for a potentially substantial display software development effort.

5.2.1.5 Improve Fleet Access to NOLAPS and/or other ETL Predictions from FNOC. The operational evaluation of NOLAPS should be completed expeditiously and, if it proves successful as an ETL forecasting system, notice of its application and availability should be promptly promulgated to all potential Oceanography Command and direct fleet users. Concomitantly a suitable operational display format(s) based upon Figure 4-05 and/or the customer survey recommendation in subsection 5.2.1.4 should be implemented. Similar action should accompany any successful development of statistical forecasting algorithms based upon NOGAPS or NORAPS output as recommended in subsections 5.2.1.2 and 5.2.1.3.

5.2.2 On-scene-related Recommendations.

5.2.2.1 Promote Passive ETL Sensor Development. The development of a passive ETL sensor system should be encouraged as exploratory research. The PRISM (Passive Refractive Index by Satellite Monitoring) project as reported by Anderson, 1981 is an example of the type of initiative which should be fostered by requirement statements and calls for research proposals.

5.2.2.2 Reanalyze the IREPS ETL Climatology. The ETL-related historical data within the IREPS climatology (the GTE Sylvania five years data) should be reanalyzed in a more sophisticated manner in order to improve the quality of IREPS Marsden square estimates. (Note: According to Ortenburger (1983), GTE Sylvania, Inc. is under contract to the government to deliver certain IBM PC Basic software which will objectively analyze (interpolate) surrounding five years data to any given geographic location. This software has obvious IREPS/TESS application and could provide the basis for the recommended Marsden square

reanalysis.)

5.2.2.3 Add an ETL Forecast Capability to IREPS/TESS. The NPS atmospheric boundary layer "slab" model, the NEPRF turbulence "closure-model" and any other likely models should receive comprehensive evaluation as on-scene ETL forecasting aids. Conceivably the Calspan Report (Mack et al, 1983) could serve as a starting point for the evaluation. Based on this evaluation, if one or more models demonstrate skill over persistence between about 6 and 24 hours, it (or they) should be added to the IREPS/TESS standard operational software.

5.2.2.4 Add a Time-series Display to IREPS/TESS. Assuming that an IREPS/TESS forecast capability is forthcoming as recommended in 5.2.2.3 above, it will be necessary to display the forecast results in a tactically meaningful way. Some sort of time-series display - similar, for example, to the top or bottom portion of Figure 4-16 - should be developed for delivery with the operational forecast model(s).

ACRONYMS AND ABBREVIATIONS

AEW	airborne early warning
AMR	Airborne Microwave Refractometer
ASW	antisubmarine warfare
C^2	command and control
CRT	cathode ray tube display
ELD	elevated duct
EM	electromagnetic
ETL	elevated trapping layer
EVD	evaporation duct
EW	electronic warfare
FNOC	Fleet Numerical Oceanography Center
FM-CW	frequency modulated, continuous wave
HP	Hewlett-Packard
IBM PC Basic	International Business Machines, Inc. Personal Computer Basic (computer language)
IREPS	Integrated Refractive Effects Prediction System
M	modified refractivity
n	refractive index
N	refractivity
NAVAIR	Naval Air Systems Command
NEDS	Naval Environmental Display Station
NEPRF	Naval Environmental Prediction Research Facility
NOGAPS	Navy Operational Global Atmospheric Prediction System
NOLAPS	Navy Operational Local Atmospheric Prediction System
NORAPS	Navy Operational Regional Atmospheric Prediction System
NOSC	Naval Ocean Systems Center
NPS	Naval Postgraduate School
OCEANCEN	Oceanography (command) center

OPEVAL	Operational evaluation
PBL	Planetary boundary layer
PMTC	Pacific Missile Test Center
SBD	Surface-based duct
SNAP	Shipboard Numerical Aids Program
TESS	Tactical Environmental Support System

REFERENCES

Anderson, K. D., 1980: Tropospheric Refractivity Profiles Inferred from RF Measurements - Passive Refractive Index by Satellite Monitoring (PRISM). Naval Ocean Systems Center, San Diego, CA, Tech. Report (NOSC/TR-629), 99 pp.

Brower, D. A., 1982: Marine Atmospheric Boundary Layer and Inversion Forecast Model. M.S. Thesis, Naval Postgraduate School, Monterey, CA, 136 pp.

Burk, S. D. and W. T. Thompson, 1982: Operational Evaluation of a Turbulence Closure Model Forecast System. Mon. Wea. Rev., 110, 1535-1543.

Davidson, K. L., G. E. Schacher, C. W. Fairall, P. Jones Boyle and D. A. Brower, 1982: Marine Atmospheric Boundary Layer Modeling for Tactical Use. Naval Postgraduate School, Monterey, CA, Tech. Report (NPS-63-82-001), 48 pp.

Fairall, C. W., K. L. Davidson and G. E. Schacher, 1981: A Review and Evaluation of Integrated Atmospheric Boundary - Layer Models for Maritime Applications. Naval Postgraduate School, Monterey, CA, Tech. Report (NPS-63-81-004), 84 pp.

Gossard, E. E., R. Chadwick and D. Wolfe, 1980: FM-CW Radar Observations in Northeastern Colorado Compared with Rawinsonde-Measured Profiles of Refractive Index. NOAA Wave Propagation Lab., Boulder, CO, Tech. Memo (NOAA-TM-ERL-WPL-57; NOAA-80081319), 40 pp.

Gossard, E. E., 1981: Clear Weather Meteorological Effects on Propagation at Frequencies Above 1 GHz. Radio Science, 16,

589-608.

Helvey, R. A., 1979: Diagnosis of Elevated Ducts by Means of Equivalent Altitude. Proceedings of Conference on Atmospheric Refractive Effects Assessment, 23-25 January 1979, San Diego, CA, Naval Ocean Systems Center, San Diego, Tech. Document (NOSC TD 260), 127-134.

Helvey, R. A. and J. S. Rosenthal, 1983: Guide for Inferring Refractive Conditions from Synoptic Parameters. Pacific Missile Test Center, Pt. Mugu, CA, Tech. Pub. (PMTC TP 000005), 36 pp.

Hitney, H. V., R. A. Paulus, C. P. Hattan, K. D. Anderson and G. E. Lindem, 1981: IREPS Revision 2.0 User's Manual. Naval Ocean Systems Center, San Diego, CA, Tech. Document (NOSC TD 481), 134 pp.

Hodur, R., 1982: Description and Evaluation of NORAPS: The Navy Operational Regional Atmospheric Prediction System. Mon. Wea. Rev., 110, 1591-1602.

Huschke, R. E. (Ed.), 1959: Glossary of Meteorology. American Meteorological Society, Boston, MA, 638 pp.

Mack, E. J., C. W. Rogers and B. J. Wattle, 1983: An Evaluation of Marine Fog Forecast Concepts and a Preliminary Design for a Marine Observation Forecast System. Calspan Report No. 6866-M-1 (Contract N00019-81-C-0102), 73 pp. plus six appendices.

Miller, G. K., W. B. Moreland and L. N. Ortenburger, 1979: Radiosonde Data Analysis III, World Contour Maps. GTE

Sylvania, Inc. Contract Report (Contract: MDA-904-78-C-0511), 36 pp.

Ortenburger, L. N., S. B. Lawson, B. J. Patterson, R. O. Heinz and D. T. Haley, 1977: Radiosonde Data Analysis II, Five Years Data, Final Report. GTE Sylvania, Inc. Contract Report (Contract: MDA 904-76-C-0233), 95 pp. plus multi-volumes of results.

Ortenburger, L. N., 1983: Personal Communication between author and L. N. Ortenburger (GTE Sylvania, Inc.) on 8 September 1983.

Patterson, W. L., 1982: Climatology of Marine Atmospheric Refractive Effects, A compendium of the Integrated Refractive Effects Prediction System (IREPS) historical summaries. Naval Ocean Systems Center, San Diego, CA, Tech. Document (NOSC TD 573), 522 pp.

Purves, C. G., 1974: Geophysical Aspects of Atmospheric Refraction. Naval Research Lab., Washington D. C., Final Report (NRL Report 7725), 44 pp.

Richter, J. H. and D. R. Jensen, 1976: New Developments in the Detection of Atmospheric Structures. Atmospheric Effects on Radar Target Identification and Imaging (H.E.G. Jeske, Ed.), D. Reidel Pub. Co., Dordrecht-Holland/Boston, MA, 357-374.

Rosmond, T. R., 1981: NOGAPS: The Navy Operational Global Atmospheric Prediction System. Fifth Conference on Numerical Weather Prediction, American Meteorological Society, Preprint Volume, 74-79.

Smith, R. W., 1974: Atmospheric Anomalies Detection Method, Navy Science Assistance Program (NSAP) Project CDL-2-73. U.S. Naval Weapons Lab., Dahgren, VA, Tech. Report (NWL TR-3062), 10 pp. plus five appendices.

Sweet, W., 1980: Assessment/Forecasting of Anomalous Microwave Propagation in the Troposphere Using Model Output. Naval Environmental Prediction Research Facility, Monterey, CA, Tech. Report (NAVENVPREDRSCHFAC TR 80-05), 42 pp.

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